PHYSIOLOGY FOR NURSES

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WITH 81 ILLUSTRATIONS

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EDWARD ARNOLD

PREFACE

SOME years ago the author wrote an "Elementary Physiology for Teachers," the aim of which was to give prominence to those anatomical and physiological peculiarities of children with which it is important for teachers to be acquainted, but which are seldom referred to in small text-books intended for the general reader. The present volume is an adaptation of the earlier work to the needs of nurses. Various sections whose importance was chiefly educational have been omitted; paragraphs, sections, and chapters have been added; and in parts otherwise unaltered a good many technical terms which were unnecessary in a book for teachers but which nurses are likely to hear in the course of their training have been included. Many references to the special features of childhood have been retained, partly because children form a considerable proportion of the patients of most nurses, and partly because so many nurses are being drawn into the service of the educational authorities. Since the publication of "Physiology for Teachers," important advances have been made in our knowledge in various departments of physiology, *e.g.* regarding the functions of some of the ductless glands, the part played by "hormones," and cerebral localisation. Care has therefore been taken to bring the present volume up to date. At the same time it has seemed best to adhere to orthodox teaching with respect to questions still under debate.

It will seem to some that a "Physiology for Nurses" ought

to be written upon a larger scale than the present work. But nurses in training have really very little time for study. Moreover, it is in accordance with sound educational teaching that the best way to study a large new subject such as Physiology is to begin by furnishing the mind with elementary facts and ideas which will enable the new knowledge to be retained and assimilated. This can best be done by mastering a small manual such as the present text-book.

The author has to thank Professor Noël Paton, Dr. Hutchison, Dr. Leonard Hill, and Dr. Alexander Hill for the use of illustrations.

W. B. D.

EDINBURGH,
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CHAPTER I

INTRODUCTORY

Anatomy deals with the structure of the body. *Physiology* is concerned with the functions of the various organs. Anatomy tells us how the body is built. Physiology tells us how it works.

Anatomy is a Greek word which signifies "a cutting up," and the chief means by which anatomy is studied in dissection. One can learn a good deal about the structure of the body by reading books, but it is very desirable that all students of anatomy should have the opportunity of seeing things with their own eyes. Otherwise very imperfect and even erroneous ideas are sure to be formed. Much assistance to the understanding may be gained by studying dissections of animals or of parts removed from animals. It is not difficult to dissect a rabbit. Full directions for doing so will be found in manuals of Practical Zoology. A rabbit differs from a man in innumerable points of detail, yet its body not only contains the same kinds of structure—bone, and muscle, and blood-vessel, and nerve—but these structures are arranged on the same plan. So close is the resemblance that one can actually compare the body of the rabbit with the human body almost bone for bone, muscle for muscle, nerve for nerve, and the corresponding structures in each are called by the same names. Only, in the rabbit the various structures are more simple, or as zoologists say, more primitive.

In dissecting an organ removed from an animal—the organs of a sheep are easily obtainable—it is often a good plan to

carry out the dissection under water. This may be done by pinning the part to be dissected to a board, and wedging the board in the bottom of a tin half filled with water. Fine parts, such as the villi of the intestine, can be seen to much greater advantage under water than otherwise.

In the study of Physiology great use is made of another method of investigation, namely, experiment. The extraordinary advances which have been made during the last hundred years in all branches of science, including the medical and surgical treatment of the sick, we owe to the experimental method. In this connection reference may be made to one form of experiment which is peculiar to Physiology and Pathology, namely, vivisection. The term vivisection literally means "cutting while alive," but the term is generally used in a wider sense to include all kinds of physiological experiments on living animals whether any cutting is involved or not. A great deal of our knowledge of physiology, of the processes of disease, and of the means by which these processes may be combated is due to vivisection experiments. Yet such experiments are open to obvious objections, and the "vivisection question" has led to an enormous amount of most acrimonious discussion between those who hold that only the total abolition of vivisection can prevent the torture of animals and those who consider it a monstrous thing that restrictions should be placed upon researches designed to bring relief to the sufferings of men and animals.

In Great Britain vivisection is only permitted in laboratories licensed for the purpose, and there only by men who hold a personal licence. The ordinary licence requires that in the case of all painful experiments the animal must be made completely unconscious by means of an anæsthetic, and killed at the conclusion of the experiment without being allowed to regain consciousness. Practically speaking the animal is killed by an anæsthetic, and the experiment is performed between the time it loses consciousness and the time it dies.

In special circumstances an animal is allowed to recover consciousness in order that the effect of the operation may be observed, but in such cases a different licence must be obtained. The present British law regarding experiments on animals may not be perfect, but reasonable people will agree with its aims, which are: (1) to protect animals from unnecessary suffering, and (2) to avoid placing undue restrictions in the path of scientific research.

Laboratories are not the only places where experiments are carried on. Hospitals are often charged with experimenting upon patients, and any hospital which is not prepared to plead guilty to the charge ought to be shut up. If a medicine is given to a patient and no one takes the trouble to watch its effects, there is no experiment. But if a medicine is ordered for a definite purpose, and pains are taken to observe carefully the exact effects produced, and to what extent they agree with or differ from the effects desired, then we have an experiment which is just as "scientific" as any experiment performed in a laboratory with equal care. Every patient admitted to a hospital is subjected to the influence of strange surroundings, strange faces, strange food, rest in bed, medicines and other forms of treatment. All these things are bound to affect him somehow. But how? There we have an experiment, continually repeated, yet never the same, provided only that the doctors and nurses are on the alert to see—what is to be seen. Every good nurse must get into the way of regarding all medical treatment as an experiment, the result of which it is her special business and privilege to watch and report.

The Microscope.—The study of physiology has been greatly assisted by the invention of many ingenious instruments, but none has been of greater service to physiology or to medicine than the microscope.

The modern microscope consists of two principal parts—the tube and the stand. In the *tube* of the microscope are

two sets of lenses. At the upper end is the *eye-piece* through which one looks. At the lower end is the *objective* which is directed to the object looked at. Most microscopes have a choice of eye-pieces and objectives so that different degrees of magnification may be obtained. The tube of the microscope is arranged to slide up and down so that the object examined may be brought clearly into focus.

The *stand* of the microscope supports the tube. Projecting from the stand is a flat *stage* to support the object examined. Beneath the stage is a *mirror* which can be tilted so as to reflect the light through a hole in the stage, thus illuminating the object from below.

In learning how to use the microscope it is better to begin by examining a few specimens with the low power objective, because the high power requires to be put much closer to the object and also requires much more careful adjustment. The object to be examined is placed on a glass slide, and covered with a clean thin glass cover. The slide is then laid upon the stage of the microscope, which must be so placed that the light from a window or a lamp can be reflected by the mirror into the tube of the microscope.

To focus the object, the best plan is to push the tube down carefully until the objective is close to the object, and then, while looking through the eye-piece, to raise the tube slowly until the object is seen clearly. The contrary plan of focusing down upon an object involves the risk of bringing the objective into forcible contact with the slide and possibly injuring one or both. As handy objects to examine in this way may be suggested the torn edge of a piece of paper, a hair from the head, fibres of wool, cotton, and linen, starch, salt, mustard. For examination with the high power a drop of blood is of special interest. A small drop of blood is obtained by pricking the finger. Near the nail where the skin is thin a very slight prick will suffice. The droplet of blood is placed in the centre of a clean slide and a perfectly clean

cover glass placed upon it *immediately*. The blood will at once spread out in a thin film, and if this is examined under the high power of the microscope the red and white corpuscles described on page 114 can be easily seen.

The Microscope in Medicine.—The microscope is in daily use in every large hospital. There are many diseases which can be diagnosed more easily and certainly by the use of the

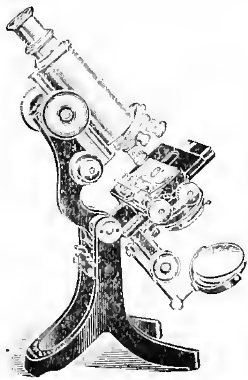

FIG. *. Microscope.

microscope than in any other way. Our modern understanding of, and methods of treating disease, are the outcome of discoveries which could not have been made or completed without the aid of the microscope. By way of example, three discoveries of fundamental importance may be mentioned:

(1) *The Circulation of the Blood.* The capillaries, which connect the arteries with the veins, were first seen in 1661 by Malpighi, who thus completed the great discovery of Harvey (see p. 100).

(2) *The Germ Theory of Disease.* Bacteria were described by Leeuwenhoek in the seventeenth century. The first germ *proved* to be the cause of a disease was the anthrax bacillus, discovered by Davaine in 1850.

(3) *The Cell Theory.* Modern physiology may fairly be said to have been built upon the theory that all the organs and tissues of the body are composed of or derived from cells. In the whole body nothing is alive but cells or what can be traced back to cells. It is therefore necessary to explain what a cell is.

CHAPTER II

THE CELL THEORY

IN ponds and ditches there may occasionally be found by those who search carefully a curious little creature which is called **Amœba**. Amœba is too small to be seen with the naked eye. The mud or stems of water weeds must be examined with a microscope. Under the microscope amœba appears a speck of semi-transparent finely granular jelly, in

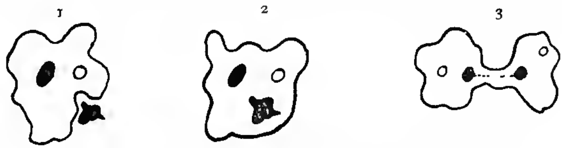

FIG. 1. Amœba. 1 and 2. Engulfing food. 3. Dividing.

the midst of which is a denser kernel which is called a nucleus. This little animal is of great interest to the physiologist, and has been very patiently studied.

Amœba has no constant shape and has no limbs, yet it is able to move about from place to place. This it does in the following way. A portion of its substance protrudes, and then the rest of the jelly gradually flows into the projecting process, so that in a short time the entire amœba occupies the position of the original protuberance. This process is repeated again and again.

If any food particles are in the neighbourhood amœba seems to be able to make its way to them, attracted in some

way which we do not understand. It possesses no mouth or stomach, but it gets over this difficulty by simply flowing around the food and engulfing it in its substance. There the food is digested, the nutriment extracted, and finally the indigestible portions are extruded.

If a sharp tap is given to the microscope the amœba is very likely to shrink up into a little ball, and remain quiet for a time. This irritability is exhibited with greater certainty if an electric shock is passed through the water in which the amœba is moving.

For its activity amœba requires a certain amount of warmth, and it also requires oxygen. If the water is too cold, or if the oxygen it contains is exhausted, the creature ceases to move.

When food is abundant amœba increases in size, but it never becomes very big, because when it finds its proportions are becoming uncomfortable it gets out of the difficulty by simply dividing into two. It is thus that reproduction is effected.

The reason physiologists are so much interested in amœba is two-fold.

(1) The **structure** of amœba helps us to understand the structure of the human body. The jelly-like material of which amœba is composed is a substance called **Protoplasm**, and protoplasm is best defined in Huxley's phrase as "the physical basis of life." There is no life in anything which is not composed mainly of protoplasm.

How protoplasm itself is composed is not thoroughly known. It is not possible to analyse it while it is alive, and as soon as it dies it breaks up into more simple substances. It must, however, be extremely complex.

Moreover, the form of amœba is noteworthy. A mass of protoplasm with a nucleus in its interior is called a **cell**, and one of the most remarkable discoveries ever made concerning the structure of the human body was that all its organs, however much they differ from one another, are made up of cells

and their products. This discovery we owe to Schwann, whose paper on the subject was published in 1838. The discovery could not have been made much earlier because cells are of such minute size that they cannot be seen without a microscope. A very common size is about $\frac{1}{2000}$ inch across, but some are smaller and some are larger than this.

(2) The second point of interest about amœba is that we find it, single cell though it be, carrying on successfully the various **functions** which in higher animals are entrusted to special organs. Amœba is irritable, in the sense of being responsive to stimuli. *Irritability* is a property of living matter which, in the higher animals, is concentrated in the nervous system. The functions of *respiration*, *digestion*, *excretion*, *nutrition*, *locomotion*, *reproduction*, are all effected by amœba within the limits of a single cell.

Higher Animals.—There are other one-celled animals besides amœba (Fig. 2), and there are others again whose

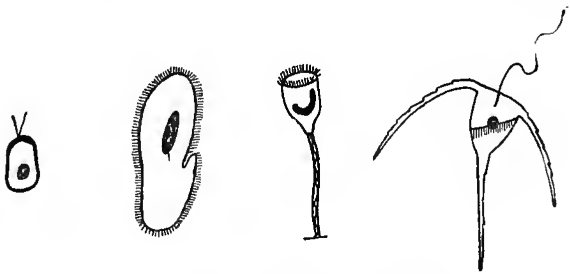

FIG. 2. One-celled animals (highly magnified).

bodies are composed of a few hundred or a few thousand cells (Figs. 3 and 4). In the higher animals, including man, all the organs of the body are built up of countless myriads of cells. Each of these cells has a more or less independent vitality, but the cells of each organ have peculiarities which fit them for the special functions which they have to perform. The appearance of the cells differs so greatly that if a small

fragment of tissue is placed under the microscope one can usually tell from what organ it comes.

In the blood there are cells called white corpuscles which closely resemble amœbæ. They float freely in the blood, and are capable of devouring solid particles just as amœba does. Under special circumstances they escape from the blood-vessels and creep into the neighbouring tissues. In cases of disease they may even attack the disease germs and eat them up.

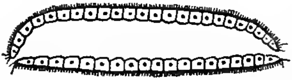

FIG. 3. An animal formed of one layer of cells.

In some organs the cells are very easily recognised. For example, in the liver we find rows and rows of cells fitted together like stones in a wall. But the liver is not a solid mass of cells. Between the rows of cells there run blood-vessels, and also minute tubes which drain away the bile.

In other places the cellular structure is less easily made out. The cells at the surface of the skin, for instance, dry up into horny scales. Bones are formed from cells, but the cells are separated from one another by the calcareous matter which makes the bone so hard. In some places the cells are greatly elongated so as to form fine threads or fibres. Muscle, for instance, is composed of long fibres, whose cellular origin is not very evident. Each fibre contains several nuclei, but it is not divided up into distinct cells (Fig. 5).

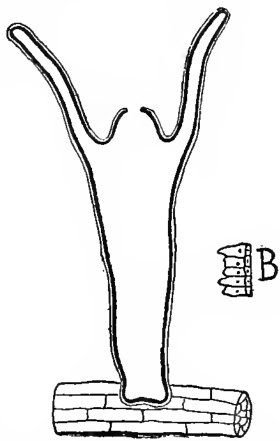

FIG. 4. Hydra—an animal formed of two layers of cells. Common in ponds. B. Part of body more highly magnified.

The body may be regarded as a **colony of cells**. Every

body cell has its own life to live just as much as amœba has Is there any advantage to the individual cell in thus living in association with other cells? Probably there is. Think, for example, of a liver cell. Such a cell, by living in the body,

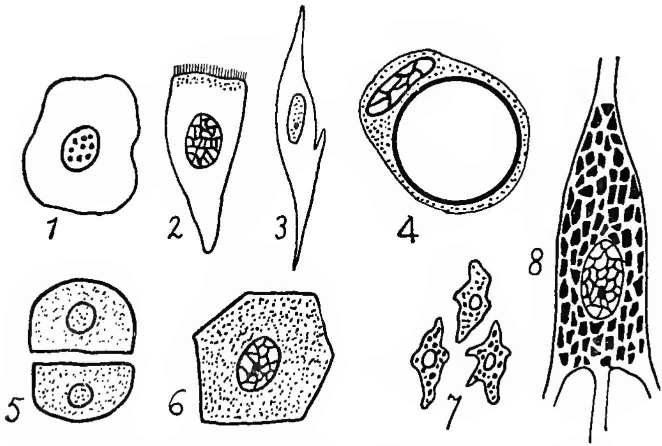

FIG. 5. Cells from the human body (all highly magnified). 1. From lining of mouth. 2. Ciliated cell from wind-pipe. 3. Connective tissue cell. 4. Fat cell. 5. Cartilage cells. 6. Liver cell. 7. Pigment cells from eye. 8. Nerve cell.

is kept warm. It is not liable, like amœba, to be frozen in winter or dried up in summer. It is well fed. It is not necessary for it to go in search of food. But in return for this it has certain duties to perform. One of its duties is to store up for the benefit of the rest of the body, the excess of nourishment which the blood brings to it after a meal. Another duty is to extract from the blood the materials necessary for the manufacture of bile. One might discuss on similar lines the lives of other kinds of cells, but after all the really important results of the association of innumerable cells specialised for particular duties is that thereby a higher form of life has been made possible, just as civilisation with its specialised trades and professions has made possible a

higher life than that of primitive times when each individual depended upon and lived for himself alone.

The Chemical Composition of the Body.—The body is composed of such substances as fat, albumin, sugar, salt and water; just such substances, in fact, as are found in food.

These various substances may be divided into two groups:

1. **Inorganic or mineral substances** which are found most abundantly in the inorganic world.

Water is the most abundant inorganic substance, and it constitutes about 70 per cent. of the body.

Sodium chloride or common salt, is the most abundant mineral salt in the blood.

Calcium phosphate and *calcium carbonate*, salts of lime, give hardness to the bones and teeth.

Iron is present especially in the colouring-matter of the blood.

2. **Organic substances** which are naturally formed by living things, whether animal or vegetable.

Of the organic substances, the most complex in composition are the *proteins*, of which albumin (white of egg) is an example. Their exact chemical composition is not known, but they contain the elements carbon, hydrogen, nitrogen, oxygen, and sulphur.

Sugar and the substances allied to it are composed of carbon, hydrogen, and oxygen.

Fat contains the same elements as sugar, but the proportion of oxygen is less.

Elements are substances which cannot be split up into simpler substances. Thus water is not an element because it can be split up into oxygen and hydrogen, but oxygen and hydrogen cannot be split up further. About seventy elements are known to chemists, but only fifteen of these are constantly present in the body.

From the point of view of physiology, oxygen is one of the most important elements, because without it no living thing

could exist. Oxygen is very abundant in the air, where it is uncombined with other elements. In the combustion of oil, or candles, or wood, or coal, the oxygen of the air unites with the carbon contained in the burning substance, and carbonic acid gas is formed. A fire cannot burn without oxygen. When a blacksmith requires a hotter fire he increases the supply of oxygen by his bellows.

In all living things a process analogous to combustion is continually going on. **Respiration** is the process by which oxygen is taken into the body. The oxygen enters into chemical union with substances in the body, and, as in the case of burning coal, heat is produced, and it is in this way that the body is kept warm.

The other chemical elements present in the body are derived from the food and drink consumed. Without a sufficient supply of food the body could not grow. But the amount of food taken is much greater than the increase in the bulk of the body. This is because a process of waste is continually going on.

When coal burns most of it disappears. Only some ash is left. Where does it go? It passes into the air as carbonic acid gas and other gases formed in the process of combustion. In like manner the combustion which goes on in the body results in the formation of carbonic acid, and large quantities of this gas are given off as a *waste product* from the lungs. Water in the form of water vapour is also given off abundantly from the lungs and skin, and other waste products are cast off from the kidneys and bowels.

CHAPTER III

NUTRITION AND GROWTH

A VERY slight study suffices to show that the various functions which amœba carries on within a single cell are, in the human body, entrusted to special organs, or rather groups of organs. Such groups of organs are called systems. The chief systems which we shall study in this book are the following: the alimentary, the respiratory, the circulatory, the skeletal, the muscular, the cutaneous, the urinary, the reproductive, and the nervous.

The organs belonging to each of these systems have their own special work to do, and if any of them fail to do it satisfactorily the other organs are apt to suffer. This is more particularly the case in children, whose rapid growth demands that the various organs should be in a state of the highest efficiency. Anything which interferes with the activity of a single organ may have more widespread and more serious consequences than would be the case in the adult.

In any class in any elementary school one may pick out children who are *ill-nourished* and *under-sized.* The usual and natural inference is that such children must be poorly fed. Unfortunately, this is too frequently the case. Nevertheless the inference is not justified without further inquiry, for bad nutrition may result from many causes. For example, a slight obstruction in the nose, such as may be caused by adenoids, may prevent a proper amount of air from reaching the lungs. The badly expanded lungs fail to supply the blood with sufficient oxygen. The impoverished blood cannot

meet the demands of the various organs, and thus the nutrition, growth, and health of the entire body are interfered with. This single instance may suffice to show that physiology is a very practical study. Intelligent obedience to the laws of health must be based upon knowledge.

Nutrition and Growth.—Nutrition is of fundamental importance with respect to growth and health. If a child is badly nourished the whole process of growth is interfered with. A child who is poorly nourished becomes thin and pale. The subcutaneous fat disappears, and with it the "roundness" which we associate with healthy childhood. There is, moreover, a striking lack of vigour and energy.

Insufficient nutrition is clearly indicated by defective height and weight. There ought to be a continuous increase during childhood in both height and weight, but if anything interferes with nutrition, growth will be impeded and the child's height and weight will be found below the normal. In some cases a child may be well nourished up to a certain time, and then something may interfere with nutrition. In such circumstances the child emaciates, but there is no loss of height. Consequently his weight will be below the normal, while his height may be that of a well-nourished child.

The table on page 16, in which the figures are taken chiefly from the Final Report (1882-3) of the Anthropometrical Committee of the British Association, shows the average height and weight at different ages.

Although growth is continuous during childhood, its rate is not uniform. It is very rapid in infancy. Then it becomes slower till about the age of five or six. From seven or eight till nine or ten growth goes on more quickly. Then follows a period of retarded growth, preceding the very rapid growth of the adolescent period. The latter begins rather earlier in girls than in boys.

This periodicity of growth is of importance to teachers, because it seems that children are more easily fatigued and

AVERAGE HEIGHT (WITHOUT SHOES) AND WEIGHT AT DIFFERENT AGES

MALES—Heavy Type. FEMALES—Light Type.

Age Last Birthday.	Height. Inches.	Increase.	Weight. Lb.	Increase.
Birth	**20.6**		**7.5**	
	20.5		7.2	
1	**29**	**8.4**	**20.5**	**13**
	28.7	8.2	19.8	12.6
2	**32.5**	**3.5**	**26.5**	**6**
	32.5	3.8	25.5	5.7
3	**35**	**2.5**	**31.2**	**4.7**
	35	2.5	30	4.5
4	**38**	**3**	**35**	**3.8**
	38	3	34	4
5	**41**	**3**	**39.9**	**4.9**
	40.5	1.5	39.2	5.2
6	**44**	**3**	**44.4**	**4.5**
	42.8	2.3	41.7	2.5
7	**46**	**2**	**49.7**	**5.3**
	44.5	1.7	47.5	5.8
8	**47**	**1**	**54.9**	**5.2**
	46.6	2.1	52.1	4.6
9	**49.7**	**2.7**	**60.4**	**5.5**
	48.7	2.1	55.5	3.4
10	**51.8**	**2.1**	**67.5**	**7.1**
	51	2.3	62	6.5
11	**53.5**	**1.7**	**72**	**4.5**
	53.1	2.1	68	6
12	**55**	**1.5**	**76.7**	**4.7**
	55.6	2.5	76.4	8.4
13	**57**	**2**	**82.6**	**5.9**
	57.7	2.1	87.2	10.8
14	**59.3**	**2.3**	**92**	**9.4**
	59.8	2.1	96.7	9.5
15	**62.2**	**2.9**	**102.7**	**10.7**
	60.9	1.1	106.3	9.6
16	**64.3**	**2.1**	**119**	**16.3**
	61.7	.8	113.1	6.8
17	**66.2**	**1.9**	**130.9**	**11.9**
	62.5	.8	115.5	2.4
18	**66.9**	**.7**	**137.4**	**6.5**
	62.4	—	121.1	5.6
19	**67.3**	**.4**	**139.6**	**2.2**
	62.7	.3	123.8	2.7
20	**67.5**	**.2**	**143.3**	**3.7**
	62.9	.2	123.4	—
21	**67.6**	**.1**	**145.2**	**1.9**
	63	.1	121.8	—

more subject to the symptoms of over-pressure during periods of rapid growth.

The Proportions of the Body.—The proportions of a child differ considerably from those of an adult, the differences being most marked in infancy. One of the most remarkable peculiarities of the infant is the relatively enormous size of the head. In the adult the height of the head is to the total height as 1 to 7; in the new-born infant it is as 1 to 4. This large size of the head is all the more notable because of the small size of the infant's face. In the early months of life teeth are absent, and the jaws are correspondingly small. The size of the infant's head is in fact due to the great size of the brain.

Another feature of interest is the great size of the arms. While the legs are relatively small, the arms are very large and muscular, albeit the baby cannot use them in any effective way. The grasp, however, is very powerful, and an ardent evolutionist was greatly delighted to discover that a new-born babe can hang by its arms from a stick placed in its grasp.

The chest of the infant is of comparatively small size, indicating imperfect expansion of the lungs. As compared to the chest the girth of the abdomen is large.

Variations in Height and Weight.—In the adult as well as the child variations in nutrition result in variations in weight. Many diseases are attended by progressive loss of weight. Increase in weight in the course of an illness is generally a good sign unless it is due to dropsy. Height is subject to very little variation, but in old age there is a slight diminution owing partly to stooping, but partly to alterations in the skeleton. In a disease called osteo-malacia characterised by softening of the bones there may be a loss in height amounting to several inches.

CHAPTER IV

FOOD AND FOOD-STUFFS

If **milk** is allowed to stand for some time, it separates into two parts, the cream and the skim-milk.

If the cream is removed and churned, it divides into butter and butter-milk.

Butter itself is not a single substance, for if it is heated it melts and gives oft a little water vapour, the butter fat remaining behind. In India butter is treated in this way, because the fat keeps better after the water has been driven off. Such fat is termed ghi.

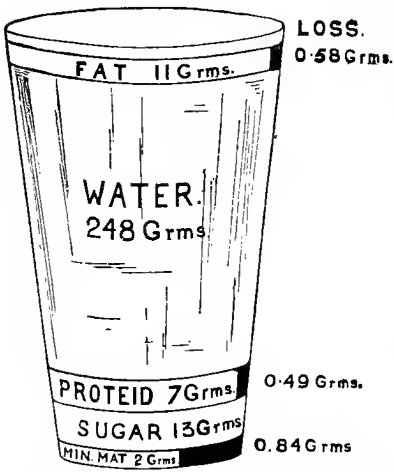

Fig. 6. Actual composition of a tumberful of ordinary milk, and percentage of loss from non-absorption. (From Hutchison's "Food and the Principles of Dietetics.")

Turning now to the skim-milk, we find that it also can be separated into several constituents.

If we warm the milk and add a little rennet, it sets in a solid mass called junket. The junket itself in a little while resolves itself into a solid curd and a watery whey. Cheese is made by separating the curd from the whey, and then

compressing it into a firmer mass. Cheese may be prepared also from whole milk. The chief component of curd, and therefore of cheese, is an albuminous substance called casein.

Whey does not consist of pure water, for if it is evaporated a considerable residue is left behind. This has a sweetish taste, and is composed chiefly of a form of sugar, but mixed with the sugar is a small amount of mineral matter.

Butter-milk resembles skim-milk in composition. That is to say, it contains a considerable quantity of casein and of sugar. It contains also the mineral matter of the milk, but it has very little fat.

We can thus divide milk into a number of different substances, and its composition may be represented in the following way:

CONSTITUENTS OF MILK

				No. in list of Food-stuffs.
Milk	Cream	Butter	Fat	3
			Water	5
			Traces of other constituents	
		Butter-milk	Sugar	2
			Casein	1
			Salts	4
			Water	5
	Skim-milk	Curds	Casein (chiefly) . . .	1
		Whey	Sugar	2
			Salts	4
			Water	5
			Traces of other constituents	

Food-stuffs.—The numbers 1 to 5 in the above table indicate that milk is a mixture of the five different kinds of material which are found in foods. All foods contain one or more of these "food-stuffs," as they are called. Some foods, like milk and eggs, contain the whole five. Other foods, like sugar, may consist of one only.

The following are the names of the different foodstuffs:

1. Proteins

EXAMPLES—Casein, in milk.
Albumin, in white of egg.
Myosin, in lean meat.
Globulin, in yolk of egg.
Fibrin, in clotted blood.
Glutin, in flour.

2. Carbohydrates

EXAMPLES—Starch, in flour, rice, potatoes.
Sugar, in honey, milk, fruit.
Cellulose, in the woody and stringy parts of vegetables (indigestible).

3. Fats

EXAMPLES—Butter fat.
Fat of beef, mutton, pork.
Vegetable fats and oils.

4. Salts

EXAMPLES—Sodium chloride (common salt).
Calcium phosphate and carbonate (lime salts) in bone.
Potassium phosphate in milk, blood.

The **proteins** are very complex in their composition. They contain not only carbon, oxygen, and hydrogen, but nitrogen and sulphur as well. Most of them contain phosphorus. The most familiar example of a protein is, perhaps, *albumin*, which is abundant in white of egg and in blood. It is soluble in water, and when it is heated it becomes solid and coagulates, as is seen when an egg is boiled. Milk contains some albumin as well as casein.

Globulin, the protein found in the yoke of an egg, is very like albumin, but it is not soluble in water unless a little salt is present as well.

Fibrin appears in blood when it is clotted, just as casein appears in milk when it curdles.

Glutin is an example of a vegetable protein. It can be obtained by tying up some flour in a cloth, and kneading it thoroughly in water. The starch of the flour is washed and

squeezed out into the water, and glutin remains behind. It is a sticky substance, and it is owing to its tenaciousness that we can make a light spongy loaf of flour. We cannot make a satisfactory loaf of rice, potato, pea, or oatmeal flour because little or no glutin is present.

Gelatin, obtained from bones and tendons, and *chondrin*, obtained from cartilage, are substances very like the proteins.

The **carbohydrates** are composed of carbon, hydrogen, and oxygen, and the two latter are present in the same relative proportions as in water. The chemical formula for starch is $C_6H_{10}O_5$; for grape sugar $C_6H_{12}O_6$.

Starch is not present in any animal food, but it is abundant in many vegetable foods, particularly the cereals, such as rice, wheat, barley, oats. Potatoes contain a large amount of starch, and so also do peas and beans. Starch consists of minute granules which can be seen by means of a microscope. When starch is mixed with water it does not dissolve, but when the mixture is heated, the granules absorb water, swell up, and rupture. In this state the starch is much more digestible than when raw. If a little iodine is added to starch, a dark blue, almost black, substance, called iodide of starch, is formed. If a glass rod is dipped in a solution of iodine and drawn across a slice of bread, a dark line is produced. One may use iodine in this way as a test for the presence of starch. Apply the test to rice, corn-flour, potato. Use a slice of raw potato and a slice of cooked potato. Note any difference.*

Sugar is soluble carbohydrate. Sugar exists in animal tissues as well as in vegetables. Heat a little soft sugar in a test-tube. Note that it melts, and then changes colour, passing from yellow, through brown to black. The dark substance thus formed is caramel, and it is sometimes used for flavouring.

Cellulose is quite insoluble in either cold or hot water.

* The *explanation* of the difference noted is that in a raw potato the starch is enclosed in small spaces bounded by cellulose, so that the iodine cannot get at the starch. When the potato is cooked the cellulose walls of the spaces are softened and broken.

Ordinary cotton is pure cellulose. Its chemical composition is that of a carbohydrate, and it would doubtless be an excellent food-stuff but for the fact that the human stomach is unable to digest it.

Fats differ from carbohydrates in that they contain very little oxygen. Like them, they contain no nitrogen. An oil is simply a fat which is fluid at ordinary temperatures. All fats become oils if they are warmed. Fats and oils may be of either animal or vegetable origin. Oil proverbially will not mix with water, but if fat or oil is shaken up with water containing soap it is broken up into minute globules, and a milky fluid called an emulsion is produced. Milk is the most perfect emulsion we know. If a drop of milk is examined under the microscope, the tiny droplets of fat can be seen floating in the surrounding fluid.

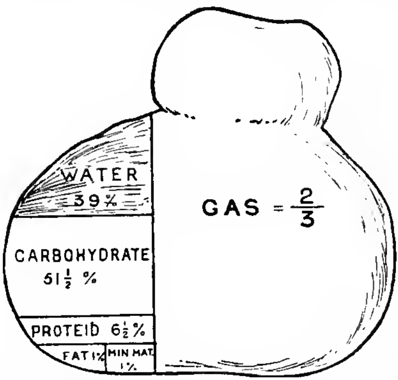

Fig. 7. Diagrammatic representation of the composition of a loaf. (From Hutchison's "Food and the Principles of Dietetics.")

The Composition of some Common Foods.—The proportion of the food-stuffs varies greatly in different articles of diet, and the value of different foods depends not only on the actual food-stuffs which are present, but upon their proportions.

The average composition of human milk as compared with cow's milk is as follows:

	Human milk.	Cow's milk.
Protein	1.7	3
Carbohydrate	6.3	5
Fat	3.2	3.5
Salts	0.3	0.7
Water	87.5	87

The following table shows the composition of some common foods. Those at the beginning of the table are specially rich in protein; then come some which are rich in carbohydrate, and lastly a few whose chief constituent is fat.

PERCENTAGE OF FOOD-STUFFS IN CERTAIN FOODS

	Protein.	Carbohydrate.		Fat.	Salts.	Water.
		Starch.	Sugar.			
Beef (lean)	20	—	—	2	3	75
Mutton (lean)	18	—	—	5	3	74
Eggs	14.8	—	—	10.5	1	73.7
Peas (dried)	23	55	2	2	2	15
Oatmeal	14.2	64.9	1	7.3	1.9	7.2
Wheat flour	9.5	74.3	1	.8	.7	13
Rice (boiled)	5	41.9	—	.1	.3	52.7
Bread	6.5	49.2	2	1	1.3	40
Potatoes	1.2	17.5	1.5	.5	.6	76
Banana	1.5	22.7		—	0.9	74
Turnip	.9	5		—	.8	91
Carrot	.5	10		—	.9	87
Cabbage	1.1	5.8		—	1.3	90
Walnut	15.5	7.4		62.6	2	4.6
Pork (fat)	9.7	—		45.5	4.4	44.4
Butter	1	—	1	82	6	10
Margarine	1.3	—	—	82.7	6.7	9.3

These percentages refer to uncooked foods (except rice and bread). In cooking the composition alters a little. For example, when beef is roasted, a considerable amount of water evaporates from it during the process, and some of the fat melts and runs off as dripping. Obviously, therefore, the proportion of protein in roast beef must be greater than in uncooked meat. Peas, when they are boiled, absorb water, and therefore the percentage of protein in cooked peas must be less than the proportion stated in the table. Such facts must be taken into account in comparing articles of diet together. One may guess at the probable composition of other articles of diet by comparing them with a similar article in the table and making allowance for obvious differences. All green

vegetables, for example, have a composition more or less like that of cabbage. Fish is obviously a kind of flesh, and therefore its composition must resemble that of meat. Its chief constituent must be protein. But white fish, such as cod and haddock, is obviously more watery than beef or mutton. Moreover, in fish, there is a greater amount of waste in the form of skin, bones, &c. Fish contains about 10 per cent. of protein. Such fish as salmon and herring are more nutritious than white fish. They contain, in addition to protein, a considerable quantity of fat.

The Uses of Food.—Food has two great uses:

(1) It *supplies the material out of which the body is built.* Even after the body has ceased to grow in bulk, food still continues to supply material to replace the waste continually going on in the tissues. Our bodies are composed of materials similar to those present in our food. "All flesh is grass," says Sir Thomas Browne, in the *Religio Medici*, "is not only metaphorically but literally true; for all those creatures we behold are but the herbs of the field digested into flesh in them, or more remotely carnified in ourselves. Nay, further, we are what we all abhor, anthropophagi and cannibals devourers not only of men, but of ourselves; and that not in an allegory, but a positive truth; for all this mass of flesh which we behold, came in at our mouths; this frame we look upon, hath been upon our trenchers; in brief, we have devoured ourselves."

(2) The second use of food is *to supply heat and energy.* This it does by the chemical changes which it undergoes within the body. Just as the combustion of coal supplies heat and energy to a steam-engine, so our food undergoes a sort of slow combustion, as the result of which the body is warmed and work is produced. Articles of diet, such as tea and coffee, which furnish neither building material nor energy are not, in the strict sense, foods.

Classification of the Food-stuffs.—The various food-stuffs may be classified according to the part they play

in the bodily economy. We may arrange them under the heads:

Tissue-formers.	Work- and heat-producers.
Proteins.	Proteins.
Mineral matter.	Carbohydrates.
Water.	Fats.

The proteins supply to the body the elements, nitrogen, carbon, hydrogen, and others. The carbohydrates and fats contain carbon and hydrogen, but no nitrogen. Oxygen is present in the various food-stuffs, but it is already combined with other elements, and is not available for the process of oxidation. The oxygen required for this purpose is derived from the air by means of respiration, and is the only element which can be taken up in a free state.

The proteins are the most important of the food-stuffs for two reasons. First, they alone supply nitrogen, and nitrogen is necessary for life. Secondly, they alone supply both building material and energy. An animal can live without carbohydrates and fats, but it must have proteins.

The Amount of Food required.—A man loses every day about 320 grammes of carbon (more than 8 oz.), chiefly in the form of carbonic acid given off from the lungs. He also loses about 20 grammes of nitrogen. He must, therefore, take sufficient food to supply this loss. All the nitrogen required must be obtained from protein, and 125 grammes of protein will make good the 20 grammes of nitrogen lost. From the table given above (p. 23), you may calculate how much of the different nitrogenous (protein) foods would have to be eaten, supposing all the nitrogen were obtained from a single source.

The carbon might also be supplied by protein, but a very much larger quantity would have to be eaten, and this would be neither convenient nor wholesome. It is because single articles of diet do not contain the different materials the body needs in the proper proportions that we are in the habit of

using a *mixed diet.* A very moderate amount of meat, which is rich in protein, can supply all the nitrogen we need, but in order to obtain sufficient carbon from meat we would have to eat about six pounds a day. This quantity would contain far more nitrogen than is required, and the excess of nitrogen would have to be got rid of. This would tax unnecessarily and harmfully the powers of the digestive and excretory organs, and disease would soon result. In practice, therefore, it has been found desirable to mix foods which are rich in protein with others which contain little protein but abundance of carbohydrate and fat.

While protein supplies a certain amount of the energy required by the body, the greater part of the energy is derived from carbohydrates and fats. Bulk for bulk fats supply more heat and energy than any other foods. Our digestive organs, however, can dispose of a comparatively small quantity of fat, hence the value of the carbohydrates which are much more digestible. Carbohydrates, moreover, are much cheaper than fats. A pound of butter, for example, costs about eight or ten times as much as a pound of sugar, but it supplies only about twice as much energy.

The building material and the energy required daily by a man might be supplied by

Protein	125 grammes
Carbohydrates . . .	500 grammes
Fat	50 grammes

A diet containing these ingredients might be constituted somewhat as follows:

Bread, 1 lb.	Fat, 4 oz.
Meat, ½ lb.	Potatoes, 1 lb.
Eggs, 2	Cheese, 2 oz.
Milk, ½ pint	Water

A man engaged in hard labour would require larger quantities of food. Many "standard dietaries" have been

drawn up similar to the above, showing how combinations of different foods can supply the bodily needs. The actual dietaries, which are based on custom and choice, are found to agree fairly closely with those based on theoretical considerations. Men have found by experience that certain articles of food go well together. In bread and butter, for instance, protein and carbohydrate are supplied by the bread, and fat by the butter. In meat and potatoes, the former supplies protein and fat, and the latter carbohydrate.

The amount of protein in the dietaries quoted above is a liberal allowance. Professor Chittenden has recently tried a number of experiments which appear to prove that health and strength can be maintained upon a much smaller quantity. He finds that 60 grammes of protein per day are sufficient for an ordinary man. The matter is one of considerable importance, for example, in arranging the dietary for the army and navy or for institutions. Most protein foods are expensive, and a low protein dietary would be economical. Further and more prolonged experiments are necessary before it can be positively asserted that such a dietary can be continued indefinitely without disadvantage. Even if it is true that the average adult eats more protein than is necessary, it does not follow that the proportion of protein should be reduced in the dietary of children, whose needs are quite different.

The Diet of Children.—The food requirements of children differ in several particulars from those of adults.

1. Children require a relatively large quantity of food (*a*) because they are growing, and (*b*) because they expend so much energy.

2. They require a relatively large proportion of protein which is needed not merely to make good the waste of tissue but to supply material for growth. A child of five requires half as much protein, half as much fat, and one-third as much carbohydrate as a full-grown man.

3. Fat is valuable on account of the large amount of

energy it supplies. It is most readily taken in the form of cream and butter. While it should be sufficiently represented in the diet, the child's natural distaste for fat and fondness for sugar probably indicate the physiological need for an easily assimilable energy-producer. This is just what sugar is. Sugar is pure carbohydrate, it is easily digested, and it supplies so much energy that it is sometimes spoken of as a muscle food. Experiments performed upon the German army show that a ration of sugar is of distinct value in diminishing fatigue.

4. For the growth of the body, and especially of the bones and teeth, a considerable amount of mineral matter is necessary. It may be supplied by giving a liberal allowance of milk and eggs. In oatmeal and the pulses (peas, beans, lentils) mineral salts are abundant.

5. A large amount of water is necessary, partly because the active habits of children dissipate much water in the breath and perspiration, and partly because water enters so largely into the composition of the body.

Milk as a Food for Children.—Look at the table showing the composition of milk and see to what extent it fulfils these requirements. It not only contains protein, but the proportion of protein to the energy-producers is greater than in the man's dietary shown on page 20. Fat is abundant in milk, constituting more than a quarter of the total solids. The carbohydrate is wholly in the form of sugar. Mineral salts and water are abundant.

Can we explain the difference between human milk and cow's milk? The chief difference, evidently, is the larger proportion of protein. A calf grows much more quickly than a baby, and nature meets its needs by supplying not only a much larger quantity of milk, but a milk which contains a larger proportion of building material. Note that the proportion of mineral matter (also a tissue-builder) in cow's milk is more than double that in human milk.

Children grow most rapidly in babyhood, and during this period they thrive on no other food so well as on their mother's milk. After the end of the first year, growth is still rapid, but not quite so rapid as before. Hence the *proportion* of protein in the diet should be somewhat reduced. This can best be done by continuing to give the child milk—cow's milk now—but giving in addition gradually increasing proportions of farinaceous matter (milk puddings) and sugar. Oatmeal is of great value because it is rich in building material as well as in carbohydrate. Eggs, also, are of great value, as they are rich in protein, fat, and salts. They contain no carbohydrate, hence their combination with starchy food in puddings is another example of how experience may produce a diet which chemistry approves.

Milk as a Food for Adults.—It is evident from what has been stated that a diet limited to milk would be unsuitable for a healthy adult because (1) it would contain too high a proportion of protein, and (2) it would be too bulky owing to the large proportion of water present. Indeed from 8 to 10 pints daily would be required. In the case of invalids, on the other hand, the dietetic requirements are often similar to those of children. Feverish patients require a large amount of fluid, hence milk is not too watery but may even be diluted still further. When the convalescent stage is reached, the body demands a large amount of tissue-building food to repair the waste which went on during the acute stage of illness. Hence the high percentage of protein makes milk a most valuable food for patients who require feeding up. Bedridden patients naturally require less food than persons who are going about, yet it may be difficult to get the patient to take even the limited quantity required. In such cases milk may be made more nourishing without materially increasing its bulk by the addition of white of egg, or sugar of milk—which is much less sweet than cane sugar—according as it is desired to increase the protein or the carbohydrate which the patient is getting.

Food Values.—Some foods, such as lean meat, are valuable chiefly on account of the building material with which they supply the body; others, such as sugar, are valuable as a source of energy. A convenient method of comparing foods is in terms of the amount of energy they are capable of producing. The unit of energy is the Calorie. A Calorie is the amount of heat required to raise the temperature of 1 litre of water from 0° C. to 1° C.* If 1 gram. of sugar is subjected to combustion in an apparatus called a Calorimeter it is found to give off 4.3 Calories, *i.e.* sufficient heat to raise 4.3 litres of water from 0° C. to 1° C. Accordingly sugar is said to have a *caloric value* of 4.3. Butter has a caloric value of about 8.6; therefore a pound of butter will supply as much energy as two pounds of sugar. All the ordinary foods have been examined in this way and tables have been published showing their caloric value. Such tables are extremely useful for the purpose of ascertaining whether a given dietary, *e.g.* the dietaries of a hospital or other institution, are sufficient, and for finding how much of one food may be substituted for another without altering the nutritive value of the diet. The nutritive value of food does not necessarily correspond to the price. A pound of margarine, for instance, will supply as much energy as a pound of butter, though the cost is less than half. A knowledge of the nutritive value of different foods is of great practical utility to nurses, especially when working among the poor, who often spend their money unwisely.†

Reference has yet to be made to the total amount of energy which the diet must furnish per day. This varies according to circumstances, but an average man doing moderate work requires about 3000 Calories. A navvy engaged in hard labour might require 4000 Calories.

* This is the big Calorie, always used in reference to food, and often spelled with a capital C to distinguish it from the small calorie, *i.e.* the amount of heat necessary to raise 1 c.c. of water from 0° C to 1° C.

† The best book on the subject is Dr. Robert Hutchison's "Food and Dietetics."

BEVERAGES

Water.—All beverages contain water, but the most important of beverages is water itself. About two-thirds of the total weight of the body consists of water, and about $4\frac{1}{2}$ pints of water are excreted daily in the urine, the breath, and the perspiration. The water lost in this way must of course be replaced.

Tea, Coffee, and Cocoa.—*Tea* was introduced into England in 1610 by the Dutch East India Company. Its price was at first ten guineas a pound. It contains an astringent substance, *tannin*, which slightly delays the process of digestion; and an alkaloid, *theine*, which stimulates the nervous system. To the latter tea owes its refreshing effect. The stimulating power of tea makes it an unsuitable beverage for children, but for adults its use, in moderation, is not only harmless, but advantageous. The practice of taking strong tea in the evening in order to ward off sleep, however, must be strongly condemned.

Coffee resembles tea in its effects, which are due to an alkaloid called caffeine. Some people find that it interferes with digestion more than tea.

Cocoa differs from tea and coffee in that it is less stimulating, and in that it is a food.

Alcoholic Beverages.—Alcoholic beverages all contain ethylic alcohol. The proportion of alcohol varies in different liquors. Thus *Ales*, prepared from malt and hops, contain from 3 to 8 per cent.; *Wines*, made by fermenting grape-juice, contain from 5 to 20 per cent.; *Spirits*, prepared by fermenting sugary solutions obtained from malted grain, and then distilling, contain from 40 to 56 per cent.

Physiological Effects of Alcohol.—Alcohol is properly described as a stimulant. The word stimulus means a whip or spur. Alcohol stimulates the nervous system, and a feeling of exhilaration is produced. In this respect it resembles tea, but it differs from the latter in that there ensues a period of

reaction and depression. This may be noticed after the drinking of very moderate quantities. In large doses alcohol is a narcotic poison, producing deep unconsciousness.

On the circulating system, also, alcohol acts as a stimulus, and it produces a feeling of warmth. This is not due, however, to any real increase in the temperature of the body, but to the fact that alcohol dilates the superficial blood-vessels, and consequently the skin is flushed with warm blood. It is a great mistake to take alcohol "to keep out the cold," for this is exactly what alcohol cannot do. On the contrary, it "lets out the heat," and increases the danger of chill.

The fact that alcohol produces a feeling of warmth while really lowering the body temperature is only one example of the curiously delusive character of its effects. Many experiments have been tried in recent years to find out the influence of alcohol on the amount of work done in a given time (*e.g.*, by compositors), on the power of memorising numbers, on the accuracy of aim of marksmen. In all cases it was found that the men experimented on thought that they were doing more work or better work after they had taken alcohol, whereas the contrary was the fact.

Alcohol and Disease.—While indulgence in large quantities of alcohol leads to such serious diseases as epilepsy and insanity, the habitual use of what many would regard as moderate quantities is responsible for a vast amount of ill-health. This is due in part to the direct effect of the alcohol on the delicate cells of the stomach, liver, kidneys, and other organs; and in part to the fact that alcohol diminishes the resistance of the body to the germs of such diseases as pneumonia and tuberculosis. These facts are well known to the Insurance Companies, which allow abstainers a substantial reduction in their premiums.

Alcohol as a Medicine.—Alcohol is still used largely as a stimulant in cases of acute illness, but its reputation, especially

in the treatment of chronic illness and of convalescence, has been steadily falling for many years. This is sufficiently shown by the following table,* about which it is only necessary to remark that it represents the practice of a large number of physicians. The remarkable fall in the amount of alcohol used in recent years cannot therefore be due to the influence of a few extremists.

Expenditure of Seven London Hospitals	1862.	1902.
On alcohol . . .	£7,712	£2,925
On milk	£3,026	£9,035

During the period there was a *slight* increase in the number of beds.

In the Royal Infirmary of Edinburgh the diminished use of alcohol has been even more remarkable. In 1890 the annual cost of wines and spirits per occupied bed was 12*s.* 10½*d.* In 1908 it was 1*s.* per bed for spirits and nothing for wine.*

* Quoted from Sir Victor Horsley.

CHAPTER V

DIGESTION

WITHIN the body the food passes through three processes—**digestion, absorption,** and **assimilation.**

The changes which the food undergoes in the **alimentary canal** constitute *digestion.* The alimentary canal is formed

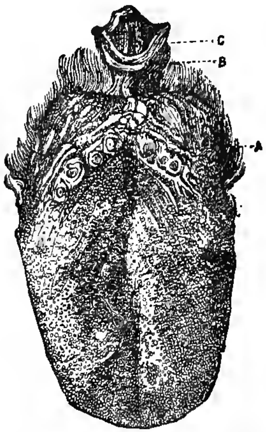

FIG. 8. Tongue, epiglottis, and opening into larynx. A. Circumvallate papillæ. B. Epiglottis. C. Vocal cords.

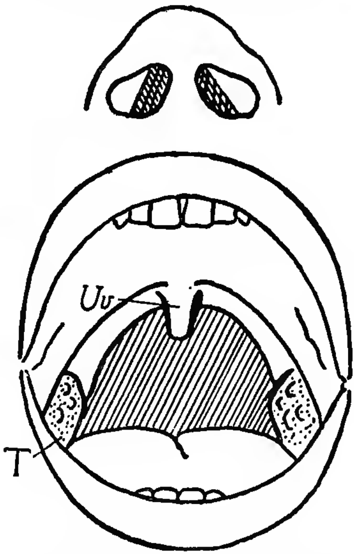

FIG. 9. The mouth. Uv. Uvula. T. Tonsil.

of several parts, namely, the mouth, the pharynx, the gullet or œsophagus, the stomach, the small intestine, the large intestine, and the rectum.

The Mouth.—The mouth is lined by a thin, red, moist skin called mucous membrane. A similar, but softer mucous membrane, lines the whole alimentary canal. The tongue is formed chiefly of muscle. The mucous membrane on its upper surface is rough owing to the presence of numerous projections called villi. Near the back of the tongue is a V-shaped row of large flat papillæ, each of which is surrounded by a deep groove. Hence these are called the circumvallate papillæ (Fig. 8). Nervous people who discover these papillæ on their own tongues are sometimes alarmed by the idea that they should not be there. The roof of the mouth is formed in front by the hard palate, and behind by the soft palate. The little tongue-like process which hangs down from the soft palate is the uvula. At each side of the mouth, below the soft palate, is the tonsil, which so frequently becomes enlarged in childhood. Quinsy is an acute inflammation of the tonsils. In the mouth the food is masticated and mixed with saliva. Thorough mastication is very important. If food is imperfectly masticated, it is much more difficult to digest.

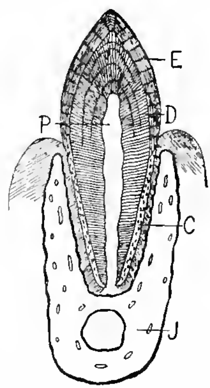

FIG. 10. Section of tooth. E. Enamel. D. Dentine. C. Cement. P. Pulp cavity for nerves and blood-vessels—not shown. J. Jaw with canal for nerves and blood-vessels.

The Teeth.—The teeth, by which mastication is effected, are fixed in sockets in the upper and lower jaws. Each tooth consists of a crown and one or more fangs or roots. The substance of the tooth is composed of a bone-like material called dentine. The crown is covered by a thin layer of enamel, which is the hardest substance in the body, distinctly harder than bone. The fang is covered by a thin layer of a bony substance called cement. Inside the tooth is a hollow filled with soft pulp. At the end of each

fang is a minute hole through which blood-vessels and nerves pass into the pulp.

In the adult there are *thirty-two teeth.* On each side of each jaw there are in front two teeth with cutting edges called *incisors;* one tearing tooth, the *canine* — very large in carnivorous animals which tear their prey, but comparatively small in man; two *bicuspid* teeth, and three *molars.* The bicuspids and the molars are adapted for grinding.

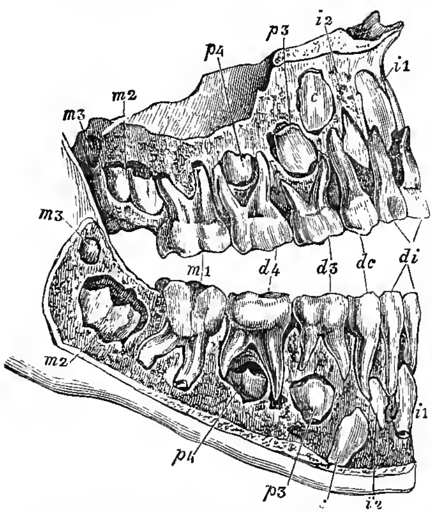

FIG. 11. Upper and lower jaw-bones of a child, sawn open to show milk teeth and the germs of permanent teeth. *di.* Milk incisors. *dc.* Milk canines. *d* 3, *d* 4. Milk molars. *m* 1. First molars. *i* 1 and *i* 2. Germs of permanent incisors. *c.* Canines. *p* 3 and *p* 4. Bicuspids. *m* 2 and *m* 3. Second and third molars.

These permanent teeth are preceded in the child by *twenty* temporary or *milk teeth.* No teeth at all are visible at birth. The *milk teeth* appear at the following ages:

Lower central incisors	(2)	6 months
Upper incisors	(4)	8–10 months
Lower lateral incisors	(2)	12 months
First milk molars	(4)	12–15 months
Canines	(4)	18 months
Second milk molars	(4)	24–30 months
	20	

Of the permanent set the first to appear are the first molars which pierce the gum at six years of age. They appear behind the temporary molars. The temporary teeth then

gradually loosen and drop out, to be replaced by those of the permanent set. The periods of eruption of the *permanent teeth* are as follows :

First molars	at 6 years
Central incisors . . .	,, 7 years
Lateral incisors	,, 8 years
First bicuspids	,, 9 years
Second bicuspids	,, 10 years
Canines	,, 12 years
Second molars	,, 14 years
Third molars (wisdom teeth) . .	17–25 years

According to this table a child is teething most of the time he is at school.

Decay of the teeth is due to fermentation produced by bacteria which live in the *débris* of food which collects between the teeth. It is apt to spread from one tooth to another. The first permanent tooth, the six-year molar, is very apt to decay because it appears before the decayed first teeth have dropped out. To prevent decay the teeth should be kept very clean. When the commencement of decay is detected the tooth should be stopped by a dentist without delay. Great care should be taken even of the temporary teeth, because if they are allowed to decay not only will the child's health suffer, but the permanent teeth will run the risk of being infected as they appear.

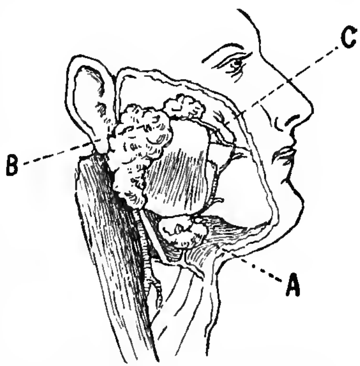

FIG. 12. Position of the salivary glands. A. Submaxillary glands. B. Parotid gland. C. Duct of parotid gland (called Stenson's duct).

Saliva.—In the process of mastication the food is not only broken up by the teeth, but is also mixed with saliva. **Saliva** is a digestive fluid which is secreted by six salivary glands

(Fig. 12). These glands are two large **parotid** glands, which lie in front of and below the ears; two **submaxillary** glands, situated under the lower jaw; and two **sublingual** glands which lie under the tongue. Mumps is an inflammation of the parotid glands. The saliva from each gland escapes into the mouth through a small tube called a duct. If the tube is traced back to the gland it belongs to, it is found to branch like a tree. At the ends of the smallest twigs are little sacs

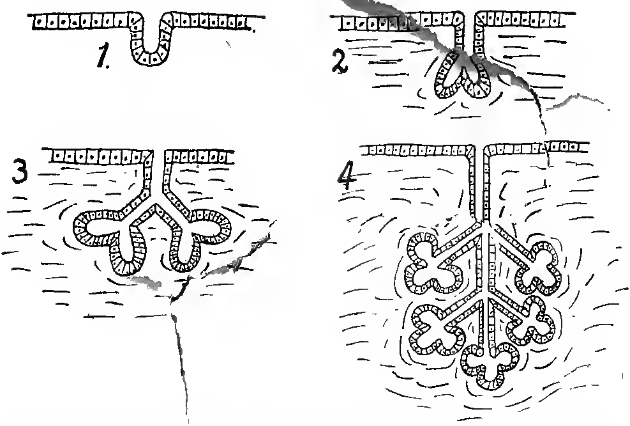

FIG. 13. Diagram to illustrate the structure of glands. 1. Simple tubular gland from mucous membrane of intestine. 2. Divided gland with duct. 3. Branching gland with duct. 4. Compound branching gland, *e.g.*, salivary gland, pancreas.

lined with cells. The saliva is secreted by these cells. The whole arrangement somewhat resembles a bunch of grapes, if you imagine all the stalks converted into hollow tubes through which the juice trickles down. In the salivary glands the little sacs are bound together by connective tissue in which run numerous blood-vessels. The blood supplies the material from which the saliva is made. The sight or smell of food stimulates the salivary glands of a hungry man and his mouth waters.

As this is the first time a gland has been mentioned, it will be well to refer to Fig. 13, which shows in a diagrammatic way the general structure of **secreting glands.** In the skin and in the membrane which lines the mouth, stomach, and intestine are innumerable glands of a simple type. The salivary glands, the liver, and the pancreas are examples of compound glands. Such secreting glands must not be compared with the "enlarged glands" often found in the neck and elsewhere in delicate children. These are lymphatic glands, which are entirely different in structure (*see* p. 117).

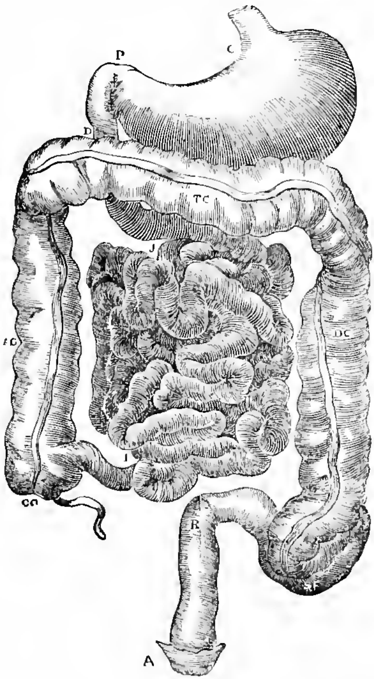

FIG. 14. The stomach and intestines. C. Œsophagus entering stomach. J, I. Small intestine. AC., TC., DC. Large intestine. R. Rectum. A. Anus. At the beginning of the large intestine can be seen the appendix.

Saliva is a watery fluid, alkaline in reaction, and slightly viscid from the presence of mucus. It contains a ferment called **ptyaline.** Ferments are organic substances capable of setting up such chemical changes as occur in the souring of milk. There are many kinds of fermentation, such as those which produce alcohol and vinegar. A very small quantity of ferment will produce a large amount of chemical change. The change produced by ptyaline is the conversion of starch into sugar—the conversion of insoluble into soluble carbohydrate. The process begins

in the mouth and continues for some time after the food is swallowed. It is the essential part of the digestion of starch. During the early months of life the saliva contains very little ptyaline, hence starchy food such as bread or rusks should not be given during this period. After mastication the food is passed back into the **pharynx**, by which it is conducted into the **œsophagus** or gullet, a muscular tube about 10 inches long, which leads to the stomach (Fig. 15).

The **stomach** is a bag-like organ in which the food remains for a considerable time. The wall of the stomach is formed of four layers. The inner layer is the mucous membrane; the second, of loose connective tissue, is the submucous coat; the third is unstriped muscle; and the outer is a thin membrane called peritoneum. All the organs of the abdomen have their surfaces covered by peritoneum. In the mucous membrane are embedded thousands and thousands of minute glands. Each gland is shaped like a test-tube divided at its deep end, and lined with cells. These glands secrete a fluid called the gastric juice, which is poured into the stomach and mixes with the food. The gastric juice is acid in reaction, and when a sufficient quantity of it has gathered it stops the action of the saliva on the starch, because ptyaline is destroyed by acids. The gastric juice contains two ferments. One is called **pepsin**, and its action is to convert the proteins into soluble peptones. The other ferment is **rennin**, and its special action is to curdle milk.

In the stomach the food is kept in constant motion by the action of the muscular coat. This helps digestion by mixing the gastric juice with the food very thoroughly. Gradually the contents of the stomach are converted into a thick fluid called **chyme**. In the chyme most of the food has already become soluble, starch having been converted into sugar, the proteins into peptones, and the fat having been melted by the heat of the body.

The conversion of a meal into chyme requires two or three or even four hours. When the chyme has been

formed it passes out of the stomach into the **small intestine.** There it mixes with the bile, secreted by the liver, and the pancreatic juice, secreted by the pancreas or sweetbread, a large gland whose structure resembles that of a salivary gland.

The Pancreas.—The pancreas is the most important of all the digestive glands. The action of the pancreatic juice depends upon three ferments :

(1) A ferment (amylopsin) like ptyalin which converts starch into sugar.

(2) A ferment (steapsin) which acts on fat and assists in converting fat into an emulsion which can be readily absorbed.

(3) A ferment (trypsin) which converts proteins into peptone.

The pancreatic juice, therefore, can complete the digestion of any foodstuffs which have escaped the activity of the saliva and the gastric juice.

Some important discoveries which have recently been made about the pancreas illustrate very beautifully the great nicety with which the functions of the organs of the body are regulated.

One of these refers to the third ferment, **trypsin.** This is a very powerful ferment like pepsin, but, unlike pepsin, it acts in an alkaline fluid. Now the pancreas is alkaline and its delicate cells consist largely of protein. Why, then, does the pancreas not digest itself? The answer to this old puzzle is that the trypsin does not become active until the pancreatic juice has mixed with a secretion from the mucous membrane of the intestine called the intestinal juice.

A more wonderful discovery still is that the proportion of the various ferments depends upon the composition of the food in the stomach. After a meal of bread and butter, for instance, the pancreas prepares a juice which is rich in the first two ferments but poor in the third, but if the meal contains butcher meat or other protein then

the pancreas prepares a sufficiency of trypsin to ensure its digestion. This is brought about by means of a substance secreted by the stomach and carried off by the blood. Some of this reaches the pancreas in the blood-stream and acts as a chemical messenger from the stomach. Such chemical messengers, which have recently been found to play an important part in physiological processes, are called "hormones," derived from the Greek word "hormao," I stir up or impel.

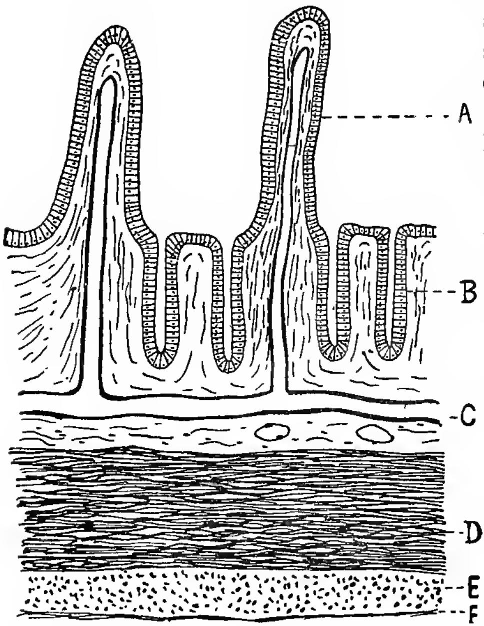

FIG. 15. Section of intestine, magnified. A. Villi covered with columnar cells. In each villus is seen a lacteal. B. Simple glands in mucous membrane. C. Soft connective tissue with lacteal. D and E. Circular and longitudinal muscular coats. F. Peritoneum.

Absorption.—Absorption takes place to a very small extent indeed from the stomach. The nutritious portions of the food are absorbed almost solely from the intestine. The small intestine is about twenty feet long, and the large intestine measures six feet more, so that there is a very large surface from which absorption may take place. The mucous membrane of the small intestine is thrown into folds—called **valvulæ conniventes**—which run across the bowel. The

whole surface has a velvety appearance, as may be best seen by cutting a small piece of intestine open and putting it in water. The velvety appearance is due to the presence of innumerable tiny projections called **villi.** The valvulæ conniventes and the villi increase greatly the amount of absorbing surface with which the food comes in contact as it moves along, propelled by the movements of the muscular fibre in the intestinal wall.

The intestine is moored to the back of the abdomen by a fold of peritoneum called the **mesentery.** In this, arteries run to the intestine to which they furnish a rich supply of blood. This blood is collected into a large vein, called the portal vein, which goes to the liver. As the blood circulates in the wall of the intestine it receives the dissolved protein and sugar absorbed by the mucous membrane. The fat in the food does not pass directly into the circulation. It is taken up by fine tubes which (owing to the contained fat) have a milky appearance, and are called **lacteals.** The lacteals collect into a larger tube about the size of a goose-quill, called the **thoracic duct.** This runs right up through the thorax and pours the absorbed fat into a large vein at the root of the neck. Thus the proteins, carbohydrates, and fats all ultimately reach the circulation.

Most of the nutritious material of the food is absorbed by the small intestine. Indigestible matter and a great deal of water pass on into the large intestine, which absorbs the water and any food which has been left by the small intestine. The large intestine begins low down in the right side of the abdomen. It passes upwards, then across the abdomen, and finally down the left side, to terminate in the rectum through which the waste material is discharged from the body. Just at the beginning of the large intestine there is connected with it a little worm-like structure, the **vermiform appendix**, inflammation of which constitutes appendicitis.

It is very important for health that the waste matters, or fæces, should be evacuated daily. Constipation is one of the most common causes of ill-health, and a very common cause of constipation is failure to cultivate regular habits in this respect.

CHAPTER VI

THE LIVER AND THE SPLEEN

THE **liver** is situated in the upper part of the abdomen It fits into the right side of the vault formed by the diaphragm. It is a solid organ, dark in colour, and of large size. Its weight is about $3\frac{1}{2}$ pounds. Underneath it is a little bag called the gall-bladder. From this a little tube passes to the duct of the liver which is called the bile duct. The bile duct opens at its lower end into the intestine. Its upper end can be traced into a fissure on the under surface of the liver. The portal vein, an artery called the hepatic artery (Greek, hepar = liver), and the bile duct all enter the liver together, and all three divide into branches which run between the cells of which the liver is composed.

The liver is a large gland and bile is the secretion formed by its cells. These cells are of comparatively large size, and are arranged in little masses called lobules. Each lobule is surrounded by a little connective tissue. The bile formed by the cells drains into the small branches of the bile duct and is conveyed to the gall-bladder where it is stored until the chyme passes into the intestine. Then the gall-bladder contracts and drives the bile on through the bile-duct. The duct from the pancreas joins the bile duct just where the latter opens into the bowel. Thus the bile and the pancreatic juice enter the intestine together. The liver secretes about two pints of bile in a day. The bile is partly a waste product, but it also assists digestion, especially of fat.

The liver has other functions besides the formation of bile. Its most important function is the formation of **glycogen.** The discovery of this function ranks as one of the great discoveries of physiology. Glycogen is a substance whose composition is similar to that of starch. It is represented by the formula $C_6H_{10}O_5$. Like starch, glycogen is insoluble in water. It is therefore sometimes called animal starch. The portal vein brings to the liver quantities of sugar derived from the digestion of the carbohydrates in the food. This sugar is not passed on directly into the general circulation, for the portal vein, unlike any other vein in the body, breaks up into capillaries, and these capillaries are distributed among the liver cells. These cells take up the sugar from the blood, convert it into glycogen, and store it up. The blood is then collected again and passes out of the liver by the great hepatic vein. The hepatic vein collects also the blood brought to the liver by the hepatic artery, and carries it to the vena cava, which opens into the heart.

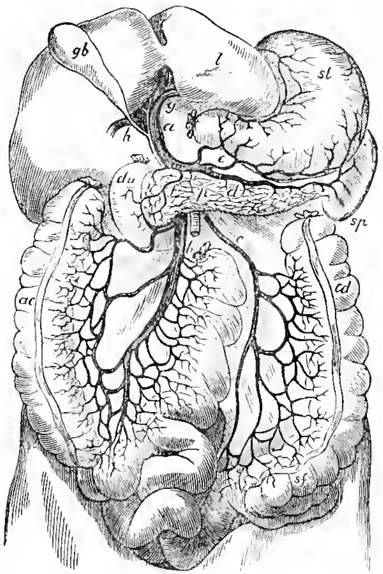

FIG. 16. Dissection showing the portal vein carrying the blood from the viscera to the liver. *l.* Liver. *gb.* Gall-bladder. *st.* Stomach. *p.* Pancreas. *sp.* Spleen. *a.* The portal vein entering the liver. Beside it is the bile duct, with a branch to the gall-bladder.

The glycogen in the liver cells is a store of nutritive material which is used up as it is required. After a meal a

great deal of glycogen is stored in the liver, and during fasting, and especially during muscular exercise, the glycogen is reconverted into sugar and passed on, a little at a time, to the general circulation. In the tissues, and especially in the muscles, this sugar is oxidised, energy is liberated, and the waste product formed, carbonic acid, is carried to the lungs and given off in the expired air. If the liver fails to store up glycogen, too much sugar passes into the blood and is excreted by the kidneys and wasted. This is what happens in the disease called diabetes.

The liver is able to form glycogen from protein as well as from carbohydrate. If a dog is well fed on lean meat its liver is found to contain glycogen. Glycogen contains no nitrogen, and when it is formed in this way, the nitrogen ot the protein becomes part of a waste substance called urea. The urea is excreted by the kidneys, and the more protein is eaten the more urea does the urine contain.

Ultimate Fate of the Food-stuffs.—It may be useful now to summarise the fate of the various food-stuffs.

Proteins are digested into peptone and absorbed by the intestine. The peptone is reconverted into a protein substance, albumin, and carried by the portal vein to the liver. Some of this passes on into the circulation and supplies building material; some is changed into glycogen and stored in the liver cells, its nitrogen being excreted by the kidneys in the form of urea.

Carbohydrates (starch and sugar) are carried to the liver by the portal vein in the form of sugar. This sugar is stored up as glycogen in the liver cells. The glycogen is changed into sugar again, and passed into the blood as it is required to produce heat and energy.

Fats are not carried to the liver, but reach the circulation directly through the thoracic duct. Fat, like sugar, undergoes oxidation in the tissues, and carbonic acid is formed as a waste product.

Mineral salts are absorbed from the intestine along with the water in which they are dissolved.

THE SPLEEN

The **spleen** is a rather pulpy organ which lies beside the stomach. Its structure consists of a dense meshwork of connective tissue containing masses of cells somewhat like the white corpuscles of the blood. It is richly supplied with blood-vessels. Its functions are not well known, and life and health are not necessarily interfered with by its removal, though the operation, which is seldom performed, is a very serious one. The spleen is one site of the formation of white blood-corpuscles. It probably destroys worn-out red corpuscles.

There has been a great deal of controversy as to the functions of the spleen, and there are some other organs in the body whose uses are as mysterious. Amongst these are the **supra-renal capsules,** two small structures, one of which is situated above each kidney. If these are destroyed by disease, death results. It has been discovered comparatively recently that these glands produce a substance called adrenalin, which is carried off by the blood and maintains the tone of the blood-vessels. Adrenalin chloride, which causes small blood-vessels to contract powerfully, is used by surgeons in certain circumstances to arrest hæmorrhage.

The spleen and the supra-renal capsules have no ducts. Hence they are sometimes called ductless glands. Another ductless gland, called the **thyroid,** is situated in the front of the neck. Goitre, so common in Switzerland, is an enlargement of this gland. If the thyroid gland is removed by operation profound constitutional changes result. The patient gradually becomes lethargic in his habits, his skin becomes thick and coarse, and his mind feeble. Sometimes a child is born with the thyroid gland lacking. Such a child does not grow like a normal baby, but becomes an idiot dwarf called

a cretin. If the child is made to eat little bits of a sheep's thyroid regularly, he improves to quite an extraordinary degree both bodily and mentally; but the development very rarely progresses as well as it would have done if the child had had a thyroid of his own.

Another organ whose functions were quite unknown till recently is the **pituitary body.** This is a rounded organ about the size of a finger-tip, and is attached to the base of the brain. It consists of an anterior and a posterior lobe closely fused together. The anterior lobe produces a secretion which regulates the growth of the body. If it becomes hypertrophied, giantism or acromegaly—a disease characterised by great enlargement of the hands and feet—results. The skulls of several well-known giants show that the pituitary body must have been enormous. The posterior lobe of this body has a different function. It produces a secretion which stimulates the kidneys, and (like adrenalin) raises the blood-pressure by contracting the small arteries.

CHAPTER VII

THE SKELETON

THE student should have access to an articulated skeleton, and should identify the various bones and bony prominences which can be felt in his own body.

The adult skeleton contains some 206 bones. These are arranged as follows:

I. **The Bones of the Head, or Skull.**—Some of these bones surround the brain and constitute the brain-box or cranium. The others are the bones of the face. All these bones are firmly united together, with the exception of the lower jaw, which is movable.

The bones of the **cranium** are eight in number:

(1) The **frontal** bone, which forms the forehead, the ridges above the eyes, and the roof of the orbital cavities (eye sockets).

(2 and 3) The **parietal** bones, two large quadrangular bones which meet each other above and form a great part of the roof of the cranium.

(4) The **occipital** bone, which forms the back of the head. The lower part of this bone curves forward and rests upon the top of the spine. It is pierced by a large hole, the *foramen magnum*, through which the spinal cord becomes continuous with the brain.

(5 and 6) The **temporal** bones, which are situated at the sides of the head. Each is united to the occipital bone behind and to the parietal bone above. The temporal bone contains the organ of hearing, and the opening which leads to

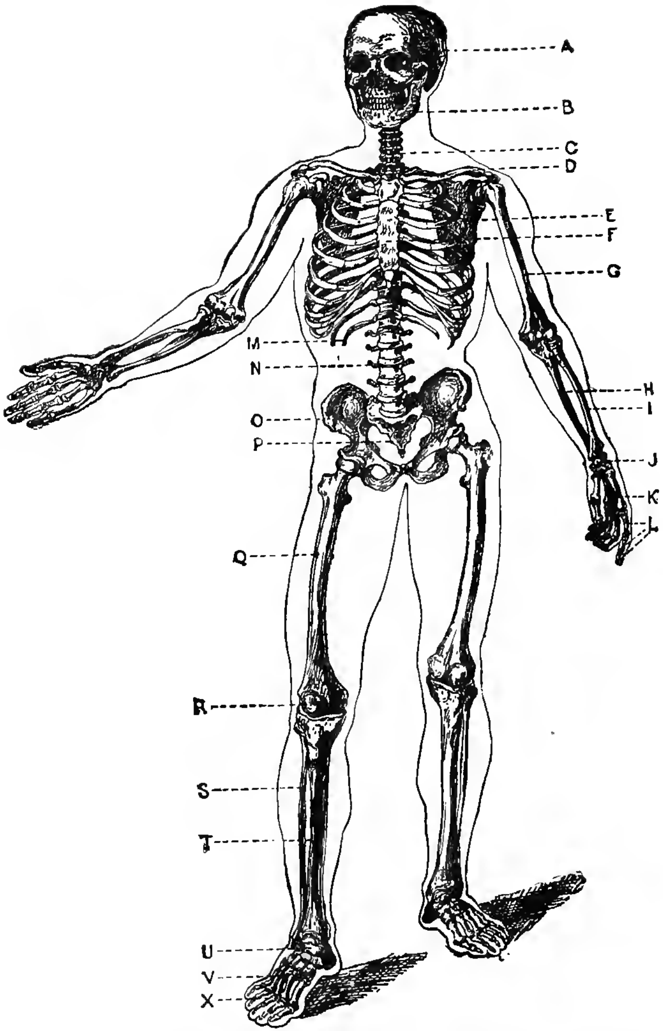

FIG. 17. The skeleton. A. Skull. B. Lower jaw. C. Cervical vertebræ. D. Clavicle. E. Scapula. F. Sternum. G. Humerus. H. Ulna. I. Radius. J. Wrist or carpal bones. K. Metacarpal bones. L. Finger bones. M. Floating ribs. N. Lumbar vertebræ. O. Hip bone. P. Sacrum. Q. Femur. R. Patella. S. Fibula. T. Tibia. U. Tarsal or ankle bones. V. Metatarsal bones. X. Toe bones.

the drum of the ear, the external auditory meatus, can easily be seen on the skull. Behind and slightly below this opening there is a considerable bony projection, the *mastoid process*, which one can feel in one's own head just behind the lower

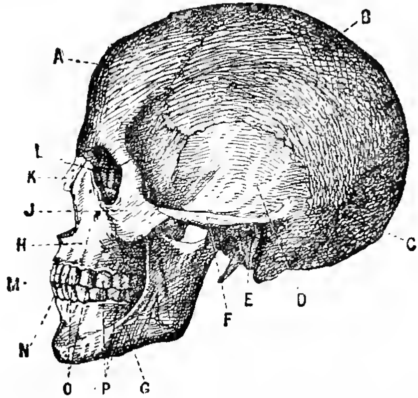

FIG. 18. Side view of the skull. A. Frontal bone. B. Parietal. C. Occipital. D. Temporal. E. Opening leading to the drum of the ear. F. Zygomatic process of the temporal bone joining J, the cheek bone. G. Lower jaw. H. Upper jaw. K. Nasal bone. L. Orbit. M. Upper incisors. N. Canine. O. Bicuspids. P. Molars.

part of the ear. Just in front of the auditory meatus is the socket for the lower jaw. From this point a process called the **zygoma** connects the temporal bone with the cheek bone.

(7) The **sphenoid** bone, which is very irregular in form. It is situated in front of the lower part of the occipital bone, and behind the ethmoid bone.

(8) The **ethmoid** bone, which is also very irregular, and which separates the cranial cavity from the nose. This bone is pierced by numerous small holes, through which pass the nerves of smell.

The **cranial cavity** is thus bounded, *in front*, by the frontal bone ; *above*, by the frontal and parietal bones ; *behind*, by the occipital bone ; *below*, by the occipital, sphenoid, and ethmoid bones ; and *at the sides*, chiefly by the temporal bones.

The **facial** part of the skull contains the following bones :

The **upper jaw** bones, right and left;

The **lower jaw**, a single bone;

Two small **nasal** bones;

The **lachrymal** bones, two little flat bones, one of which lies in the inner side of each orbit;

The **palate** bones, one of which lies behind each upper jaw bone, and helps to form the hard palate;

The **cheek** or malar bones, which bound the orbits below and to the outer side.

The cavity of the **nose** should be carefully examined. It is divided into two passages by a bony septum, the **vomer.** These passages pass backwards and open behind at the edge of the hard palate. On the outer wall of each passage can be seen the very delicate scroll-like **turbinate** bones, which thus project into the cavity of the nose (*see* Fig. 47).

II. **The Bones of the Neck and Trunk,** namely, the *vertebral column*, the *ribs*, and the *sternum*.

(1) The **vertebral column,** or **spine,** is composed of a series of separate bones, the *vertebræ*, arranged one above another. Of these bones there are seven cervical or neck vertebræ, twelve dorsal vertebræ, and five lumbar vertebræ. Below the lumbar vertebræ is a bone called the *sacrum*, which is formed of five vertebræ fused together. Below this again is a little bone called the *coccyx*, which is formed of, usually, four very rudimentary vertebræ fused together.

Structure of a Vertebra.—Each vertebra consists of a very solid disc-like mass of bone called the *body*. Behind this is the vertebral *arch* connected with the body by two pillars. From each side of the arch there projects outwards a *transverse process*, and from the centre of the arch there projects backwards a *spinous process*. The bodies of the vertebræ are united to one another by thick pads of a tough, somewhat elastic substance called fibro-cartilage. These pads are the *intervertebral discs*. The arches of contiguous vertebræ are

connected by *articular processes* between which are definite joints.

The vertebræ are so arranged as to form an immensely strong but flexible column. The arches lying above one another form a canal, in which lies the spinal cord. The

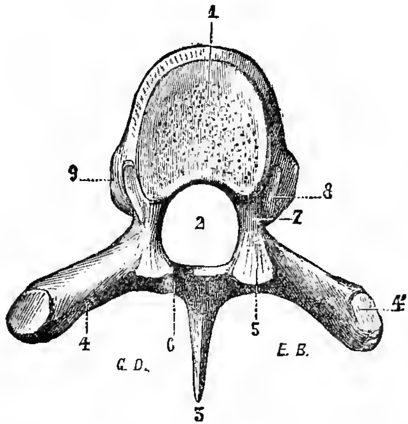

Fig. 19. Thoracic vertebra, top view. 1. Body. 2. Hole which forms part of vertebral canal. 3. Spinal process. 4. Transverse process. 5. Surface which articulates with next vertebra above. 8 and 4'. Surfaces which articulate with a rib.

spinous processes project downwards as well as backwards, and thus help to protect the spaces between the arches. The spinous processes can be felt by running a finger down the middle of the back, and so the vertebræ can be counted.

In the different regions of the spine—neck, back, loins—the vertebræ have special characteristics. Note, for instance, the differing forms of the spinous processes. The largest and strongest vertebræ are those of the lumbar region. The dorsal vertebræ can be recognised by the small, smooth surfaces to which the ribs are attached.

Peculiar Vertebræ.—Several vertebræ present individual peculiarities.

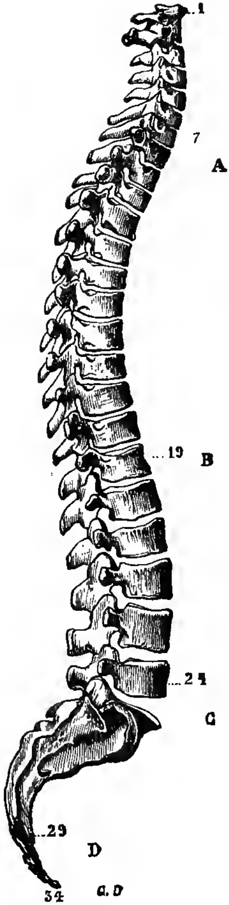

Fig. 20. The spinal column. 1–7. Cervical (7). 7–19. Thoracic (12). 19–24. Lumbar vertebræ (5). 24–29. Sacrum (= 5). 29–34. Coccyx (= 5). Notice the bends of the column.

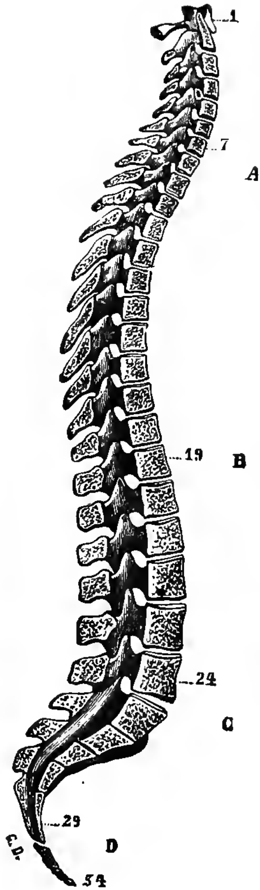

Fig. 21. Spinal column sawn asunder along its length, showing the canal which receives the spinal cord, and the holes between the vertebræ through which pass out the nerves.

The **first cervical vertebra** bears the head, and is called the **atlas.** Upon its upper surface are two smooth hollows. Into these fit two nobs on the under surface of the occipital bone, one on each side of the foramen magnum. At the joint so formed the *nodding movements* of the head take place.

When the head is rotated from side to side, however, the movement does not take place at this joint, but the atlas vertebra rotates with the skull, the movement thus being effected by rotation of the first vertebra upon the second.

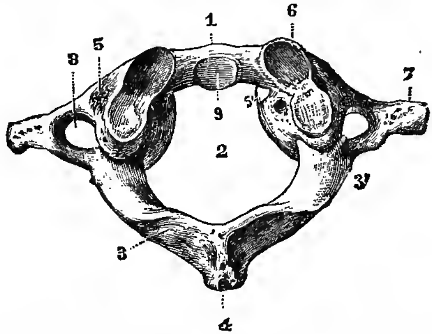

Fig. 22. Atlas vertebra, top view. 1. Body. 2. Hole, part of vertebra canal. 4. Spinal process. 6. Surfaces which articulate with the base of the skull. 7. Transverse process. 9. Surface articulating with the peg-shaped process of the axis.

This rotation takes place round a pivot-like process which projects upwards from the body of the second vertebra. Hence this vertebra is termed the **axis.** To make room for this process the first vertebra has no proper body, but merely an arch of bone which lies in front of the *odontoid process*, as the pivot is called. The joints between the contiguous surfaces of the atlas and axis are very loose as compared with those between the other vertebræ, and thus a considerable range of movement is possible.

The **seventh cervical vertebra** is characterised by the marked prominence of its spinous process. You can feel this by running a finger down the back of your neck.

The **sacral vertebræ**, as has been stated, are fused together into a single bone, on which, however, the divisions corresponding to the original vertebræ can be made out. The transverse processes have become enlarged and fused together to form a strong mass of bone on each side. To this part of the sacrum the hip bone of the corresponding side is firmly united.

The little **coccyx** is the rudiment of a tail.

Before leaving the vertebræ examine for a moment **the spine as a whole.** Looking at the spine from the front, notice how the bodies of the vertebræ diminish steadily in size from the lowest lumbar right up to the fourth dorsal. Thus these vertebræ form a pyramid resting upon the sacrum. Notice, also, the thickness of the intervertebral discs. These discs together measure nearly one-fourth the whole length of the spinal column, and by their elasticity they greatly diminish shock or jar in walking, running, and jumping.

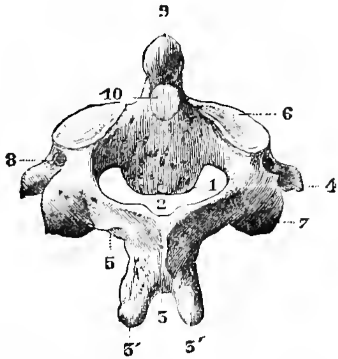

Fig. 23. The axis vertebra, top view. 1. Body. 2. Hole, part of vertebral canal. 3. Spinal process. 4. Transverse process. 6. Surfaces which articulate with atlas. 9. Odontoid or peg-shaped process.

Now regarding the spine from the side, observe the forward curve in the cervical region, the backward curve in the dorsal region, and the forward curve in the lumbar region. These curves, like the intervertebral discs, diminish jar, by forming a series of springs, while the pyramidal form of the column and the presence of the curves make the spine much stronger than a straight inelastic pillar would be.

Although the amount of movement between any two vertebræ is very slight, the total amount of movement of which

the spine is capable is considerable. But this will be further considered when we deal with the joints.

(2) The **ribs** are twenty-four in number, in twelve pairs. The ribs articulate with the bodies and with the transverse

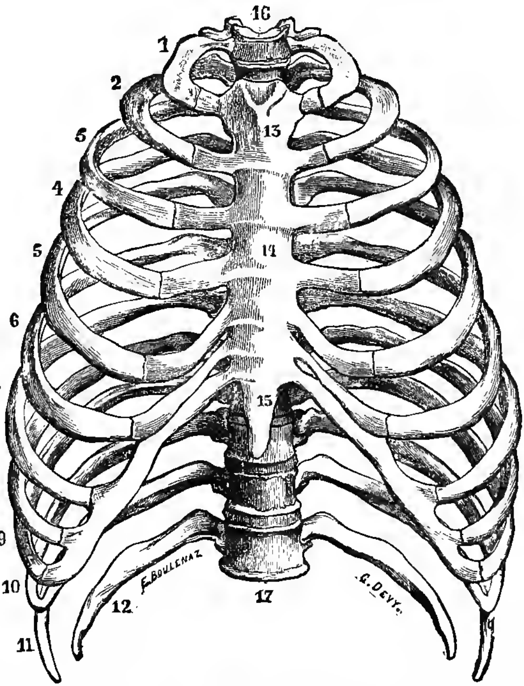

FIG. 24. The bony thorax. 1–12. Ribs. 13–15. Sternum. 13. Manubrium. 14. Body. 15. Ensiform cartilage. 16–17. The thoracic part of the spinal column (12 vertebræ).

processes of the dorsal vertebræ, and then sweep round to meet the sternum in front. The upper seven ribs of each side are connected with the sternum by pieces of cartilage. These are called the *costal cartilages.* The costal cartilages of the next three ribs are joined first to one another, and then to that of the seventh rib, so that they are connected with

the sternum indirectly only. The two lower ribs are shorter than the others, and do not reach the sternum at all. They are called floating ribs.

(3) The **sternum** or **breast bone** is a flat bone, which lies in the front of the chest. The sternum, the ribs, and the dorsal vertebræ form the skeleton of the *thorax*, a cage-like structure of a conical shape, which is narrow above and broad below, and which during life contains the heart and lungs as well as other important organs.

III. **The Bones of the Upper Limb** are:

(1) The **clavicle** or **collar bone,** an *f*-shaped bone, which can easily be felt at the base of the neck. Its inner end is joined to the sternum, and its outer end to—

(2) The **scapula** or **shoulder blade,** a triangular bone which can be felt in the back, more readily if the arm or shoulder be moved. The scapula is a flat bone, but a prominent ridge or *spine* runs across its surface, and this ridge ends in the stout *acromion* process to which the clavicle is attached. Projecting from the upper border is another process called the *coracoid.* In life it can be felt underneath the collar bone.

(3) The **humerus** or **arm bone** is a long, strong bone, which articulates above with the scapula and below with the bones of the forearm. Notice the projecting processes just above the lower end of the humerus. These are the internal and external *condyles.* They give attachment to important muscles. Feel them in your own arm.

(4) The **radius** and **ulna** are the bones of the forearm. Note the small head of the radius which articulates with the humerus, and the large lower extremity which carries the wrist.

The **ulna** is very large at its upper end, and quite small below. Note that the sharp point of bone which forms the tip of the elbow belongs to the ulna. From this point the ulna can be traced right down to the wrist, as it lies just under the skin. Note that the radius lies to the thumb side, and the ulna to the little finger side of the forearm.

(5) The **carpal**, or wrist bones, are eight little bones arranged in two rows. They cannot be separately distinguished during life. Their names, starting from the thumb side, are as follows: First row: **scaphoid, semi-lunar, cuneiform, pisiform.** Second row: **trapezium, trapezoid, os magnum, unciform.**

(6) The **metacarpal** bones are five in number, one for the thumb, and one for each of the fingers. They lie in the palm of the hand.

(7) The **phalanges** number fourteen, two for the thumb and three for each finger.

IV. **The Bones of the Lower Extremity** are:

(1) The **hip** or **innominate** bone, which is a very large, strong bone, of a curious, irregular shape. Each bone is firmly united to the sacrum behind and to its fellow in front. The hip bones and sacrum together form a large basin-like cavity, the pelvis. The upper edge of the hip bone is called the crest. In front the crest forms a projection called the anterior superior spine of the hip bone. This is easily felt in the living body and is an important surgical "landmark." From this point surgeons often measure the length of the leg. On the outer side of the hip bone note the large socket called the acetabulum for—

(2) The **femur** or **thigh** bone, which is the longest bone in the body. The large, round head of this bone is connected to the shaft by a neck which slopes downwards and outwards to the *great trochanter*, the projection which one feels about four inches below the crest of the hip bone. A little lower, and on the inner side, is a smaller projection, the *small trochanter*, to which powerful muscles are attached during life. The shaft of the femur is not quite vertical, but slopes slightly inward. The lower extremity is very large, and forms the knee joint by articulating with—

(3) The **tibia or shin** bone, whose sharp edge can be felt running down the front of the leg.

(4) The **patella** or **knee-cap** is the little bone which can be felt in front of the knee.

(5) The **fibula** is a long thin bone which lies on the outer side of the tibia, with which it is connected above and below. Note that this bone does not enter into the formation of the knee joint, nor does it bear the weight of the body. The prominences which are to be felt at the inner and outer sides of the ankle are the lower ends of the tibia and fibula respectively. They are technically known as the internal and external malleolus.

(6) The **tarsal** bones, which correspond to the carpal bones of the wrist, are seven in number. The one which articulates with the tibia and fibula is called the **astragalus,** and the bone which projects backward into the heel is called the **os calcis.** In front of the astragalus is the **scaphoid** bone, and in front of this are three **semi-lunar** bones which articulate with the metatarsal bones of the three inner toes. In front of the os calcis is the **cuboid** bone which articulates with the metatarsal bones of the fourth and fifth toes (*v.* JOINTS—Chap. VIII).

(7) The **metatarsal** bones and the phalanges correspond in number to the similar bones in the hand.

CHAPTER VIII

THE JOINTS

THE joints which connect the various bones together differ considerably in structure. They may, however, be considered as forming two great classes—imperfect and perfect.

Imperfect joints allow of little or no movement. Examine the vault of the skull and observe how the edges of the bones are dovetailed together by very fine serrations. The bones look as if they had been sewed together, hence such a union is called a suture. Sutures permit of no movement, and it is very difficult to separate the bones so united. Indeed, they cannot be separated without the breaking of many fine spicules of bone. As life advances, the union between the various bones of the skull becomes more and more intimate, and in later years the bones of the cranium may be so merged together at their edges that the original sutures cannot be distinguished.

Another form of imperfect joint is found in the connection of the bodies of the vertebræ by means of a disc of cartilage which, by its elasticity, permits of slight movement.

The connection of the ribs with the sternum by means of the costal cartilages forms a joint of a similar kind. In early life the cartilages are very flexible, but they become more and more rigid as the years go by.

Perfect joints permit of movement by allowing the parts of the bones which are in contact to slide over one another. These joints are of the following varieties :

(1) *Hinge joints*, which allow backward and forward movement. Examples: Knee, elbow, ankle.

(2) *Gliding joints*, which allow a small amount of sliding movement. Examples: The joints between the articular processes of the vertebræ, and between the carpal, and the tarsal bones.

(3) *Ball and socket joints*, which allow movement in all directions. Examples: Shoulder, hip.

(4) *Pivot joints*, which admit of rotation only. Example: The atlo-axoid joint (p. 56).

The Structure of a Perfect Joint.—In this type of joint the ends of the bones which meet together are covered by a thin layer of remarkably smooth cartilage. This should be examined in a fresh bone. In the prepared skeleton the cartilage has shrivelled up into a horny substance, and has lost much of the fine polish it originally possessed.

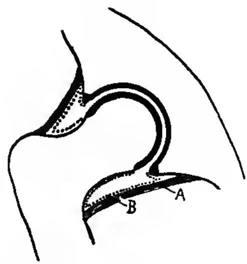

Fig. 25. Diagram of a section through the hip joint. A. Capsule. B. Synovial membrane (dotted). The cartilage covering the head of the bone is really in contact with that lining the socket.

Each joint is enclosed in a loose bag of fibrous tissue called the capsule. The capsule is attached to the bones, and parts of it are thickened to form strong bands or ligaments which pass from one bone to the other, and check excessive movement. Except over the surface of the cartilages the joint is lined by a very fine membrane. This is called the synovial membrane. It secretes a small quantity of fluid which lubricates the joint, and so facilitates movement.

Let us now study the joints in the different regions of the body.

The Joints of the Skull.—As has been already mentioned, the only movable joint in the skull is that between the lower jaw and the temporal bone. This joint is of the hinge type

but it is a rather loose hinge, as it permits of the jaw being moved from side to side, and also backwards and forwards so that the lower incisors can be made to bite in front of the upper. These movements are important, as they make the thorough mastication of the food possible. In carnivorous animals such as the cat or the tiger, which do not grind their food, this joint is a perfect hinge.

The Joints of the Trunk.—The joints of the spine have been described already, but we have still to consider the movements of which the spine is capable. The spinal column, as a whole, is very flexible, especially in childhood. A healthy child sitting on the ground with his legs drawn up can easily bend forward until his head rests on his knees. In this posture the spine presents a beautiful single curve, an almost perfect semicircle, on which, however, can be seen a slight prominence at the root of the neck formed by the spinous process of the seventh vertebra. There is a well-known piece of sculpture representing a boy asleep in this posture. The spine can also be bent backwards, and to either side.

These movements—forward and backward flexion, and lateral flexion—do not exhaust the capabilities of the spine. It can also be twisted to some extent. While sitting on a seat try to look behind you as far as possible. The greater part of the movement takes place by turning the head—at the joint between the atlas and axis vertebræ. But if you make at all a vigorous effort to look backwards you can feel the twisting strain right down the back.

Any child who appears unable or unwilling to bend the spine freely, or who complains that certain movements, such as stooping, cause pain, should be examined by a surgeon, as such symptoms may indicate spinal disease.

The joints between the ribs and the bodies and transverse processes of the vertebræ are perfect joints. The movements of the ribs will be described in the chapter on respiration.

THE JOINTS OF THE UPPER LIMB

The **clavicle** articulates at its inner end with the **sternum**, and at its outer end with the **scapula.** Place one hand over the opposite clavicle and raise the shoulder. Note the movement of the clavicle. In shrugging the shoulders the movement takes place at the sterno-clavicular joints. Again, in throwing the shoulders forward or back the movement takes place at the same joints.

As the outer end of the clavicle is firmly attached to the scapula, the latter bone necessarily follows the former in its movements. Place one hand behind the back, and feel the lower angle of the opposite scapula. It can easily be felt by moving the shoulder slightly. Now shrug the shoulder, and the angle of the scapula will be found to travel upwards for about a couple of inches.

Lower the shoulder and find the position of the angle again. Throw the shoulder forward, and notice how the scapula is carried forward also. These movements of the clavicle and scapula should be studied on the living subject without clothes.

The **shoulder joint** is the joint between the scapula and the humerus. The upper end of the humerus has a smooth round head, rather less than half a sphere, which fits into a shallow socket on the scapula, thus forming a ball and socket joint.

At the shoulder joint the arm can be stretched straight forward (extension); it can be brought back to the side (flexion); and it can be stretched backwards. It can be raised sideways (abduction); and lowered again (adduction). The humerus can also rotate on its own axis. When we are writing a letter the movement of the hand along the line is effected *chiefly* by rotation of the humerus, not, as one might imagine, by a movement of the elbow joint.

One other movement of the arm must be described, namely, elevation. When we stretch the arm up as far as possible we raise the shoulder also. Obviously we must be able to reach

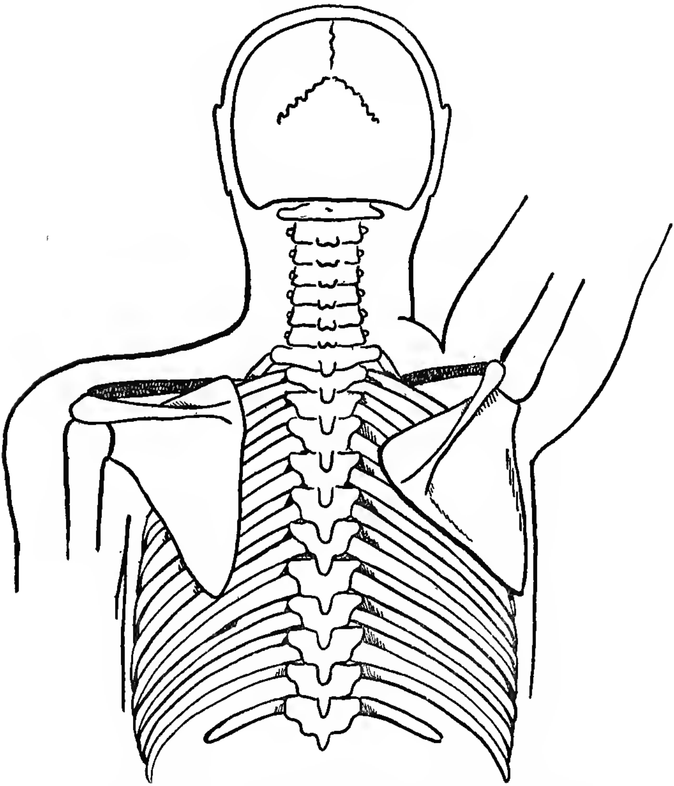

FIG. 26. To show that, when the arm is raised, the scapula and collar bone are raised also.

higher if we elevate the shoulder joint. Elevation of the arm is therefore a combined movement involving motion at the shoulder and at the sterno-clavicular joints. Find out for

yourself, by feeling your collar bone or scapula, or by observation in a mirror, how high you can raise the arm by movement at the shoulder joint alone.

The **elbow joint** includes the ends of the humerus, the ulna, and the radius. The upper end of the ulna is shaped

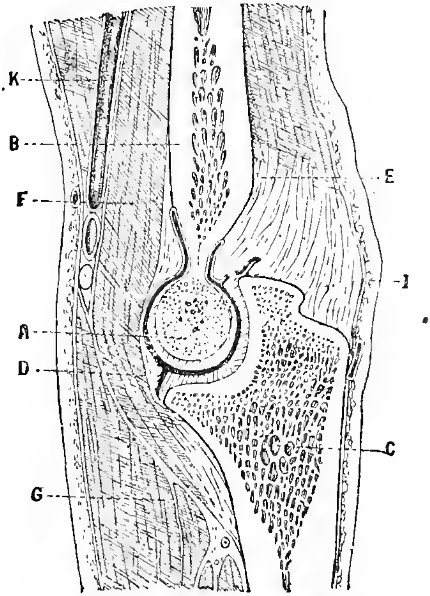

FIG. 27. Section of Elbow Joint. A. Extremity, and B. Shaft of humerus. C. Ulna. D. Synovial membrane. E. Triceps. F. Biceps, and G. Flexor muscles. I. Skin. K. Brachial artery.

something like a chair. The humerus sits in this chair, and fits it so accurately that the only movements possible are flexion and extension. Observe on the skeleton how the chair-back—the olecranon process—prevents over-extension of the forearm. We cannot bend our elbow back.

The radius articulates with the humerus. and is also

attached to the ulna above and below. Obviously the radius accompanies the ulna in the movements of flexion and extension of the elbow. Now look at the joint between the humerus and the radius (part of the elbow joint). A little ball-shaped elevation on the humerus fits into a shallow socket on the top of the radius. What is the meaning of a ball and socket joint here?

It means that the radius, although bound to the ulna, is yet capable of freer movement than that bone.

Lay your forearm, palm upwards, on the table in front of you. In this, which is called the supine position, the radius and ulna lie parallel to one another, the radius being to the outer side. Now turn the hand palm downwards. This movement is called pronation, and it is not difficult to discover that in carrying it out the lower end of the radius, which can easily be felt at the wrist, rotates round the lower end of the ulna, and comes to lie at its inner side. The relative position of the upper ends of the bones is not altered. Consequently in pronation the radius lies across the ulna. Demonstrate this on the skeleton.

In these movements of pronation and supination the head of the radius must obviously rotate on its own axis, and we can now see the advantage of the ball and socket arrangement at the elbow, which not only permits of the movements of pronation and supination, but permits of them at any stage of flexion or extension of the forearm.

The **wrist joint** permits of very free movement. Thus the hand can be flexed, extended, or dorsi-flexed (*i.e.*, bent backwards). It can also be bent to the ulnar side (ulnar flexion), and to a much less extent to the radial side (radial flexion). The limitation of flexion to the radial side is due to the prominence of the lower end of the radius, which projects fully half an inch lower than the end of the ulna. These various movements take place chiefly between the radius and ulna above and the first row of carpal bones below. Between the

carpal bones themselves, and between the second row of carpal bones and the metacarpals, there are small joints lined by synovial membranes, but the amount of movement possible is very slight. The metacarpal bone of the thumb alone can move freely.

The movements of the fingers are flexion and extension; abduction and adduction. The thumb is also capable of being opposed to any of the other digits. The power of opposing the thumb is the chief characteristic of the human hand. The only other animals which have an opposable thumb are the monkeys, and their ability to oppose the thumb is less perfect than ours. On the other hand many of the monkeys are able to oppose their great toes.

THE JOINTS OF THE LOWER LIMB

The **hip joint,** like the shoulder, is a ball and socket joint. It differs from the shoulder joint chiefly in the great depth of the socket. During life the socket is even deeper than in the skeleton, because it has a thick rim of cartilage. The depth of the socket is obviously a great advantage because it makes it very difficult for the head of the thigh bone to slip out of place, an accident which would be of frequent occurrence if the socket were as shallow as that of the shoulder. Within the joint, stretching from the hip-bone to the head of the femur, is a stout fibrous band called the round ligament or *ligamentum teres*. The movements which take place at the hip are flexion, extension, extension backwards, abduction, adduction, and rotation. These movements are very free, but not quite so free as those at the shoulder.

The **knee joint** is a hinge joint between the femur and the tibia. The upper end of the tibia on which the femur rests is broad and has two shallow depressions, the articular surfaces. These are deepened by semicircular bands of fibro-cartilage. The lower end of the femur swells out into

two large articular surfaces separated behind by a deep depression, but continuous with one another in front. These rest upon the depressions on the tibia and glide over them when the knee is bent. Thus in the straight position of the leg the front parts of the articular surfaces of the femur rest upon the tibia ; the hinder parts when the knee is bent.

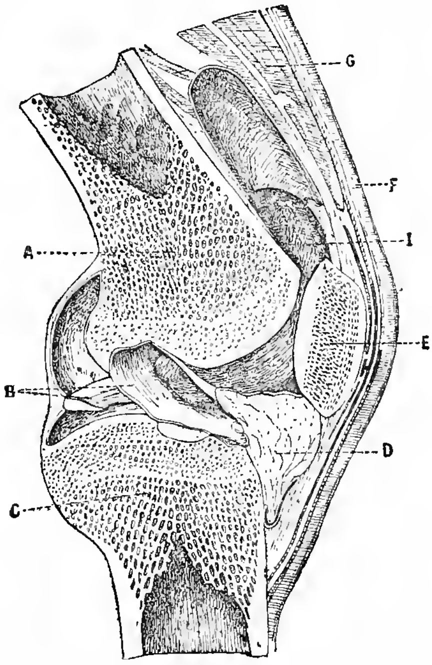

FIG. 28. Section of Knee Joint. A. Femur. B. Crucial ligaments. C. Tibia. D. Pad of fat. E. Patella. F. Skio. G. Muscles. I. Joint cavity extending under thigh muscles.

Within the knee joint, stretching from the femur to the tibia, are two strong bands or ligaments. These cross one another like the letter X and are called the *crucial ligaments*. When the limb is straight these bands become taut and prevent the leg bending forward at the knee-joint.

In front of the knee, and entering into the formation of the joint, is the knee-cap or patella. A strong band, the *ligamentum patellæ*, passes from the patella to the front of the tibia. If the leg is stretched out and the heel supported on the ground or on a chair the patella can be moved about pretty freely by the fingers. But the moment the leg is raised so as to lift the heel from its support the patella is felt to become fixed, and the ligament of the patella can be distinctly felt to rise up and become taut.

The fibula does not form any part of the knee joint, nor does it bear any part of the weight of the body. Its upper end articulates with the tibia below the level of the knee, and its lower end articulates with the tibia again above the ankle. The bony prominences at the outer and inner sides of the ankle are the lower ends of the fibula and tibia respectively.

The **ankle joint** is formed by the tibia and fibula above, and one of the tarsal bones, the *astragalus*, below. It is a hinge joint permitting of flexion and extension of the foot. When the foot is turned outwards or inwards the movement takes place, not at the ankle, nor yet at the knee, but at the hip, as may be easily verified by turning the foot out and in while the hand feels the great trochanter.

Between the various tarsal, metatarsal, and phalangeal bones are joints similar to those found in the hand, and allowing of similar movements, except in the case of the great toe, whose movements are very restricted compared with those of the thumb.

The **structure of the foot** deserves fuller study, for the more we study it the more wonderful do we find the mechanism whereby in a single organ are combined great strength, mobility, and resilience.

The weight of the body is borne on the heels and the balls of the toes, and between the balls of the toes and the heel the tarsal and metatarsal bones are arranged in the form of an arch. This arch is a combination of two arches, an outer and

an inner. The bones on the outer side of the foot are very strong, and form a low arch, so low indeed that it rests on the ground when the foot is pressed on very heavily, for instance, when we carry a heavy load. Ordinarily, however, when we stand, although the skin of the outer part of the sole of the

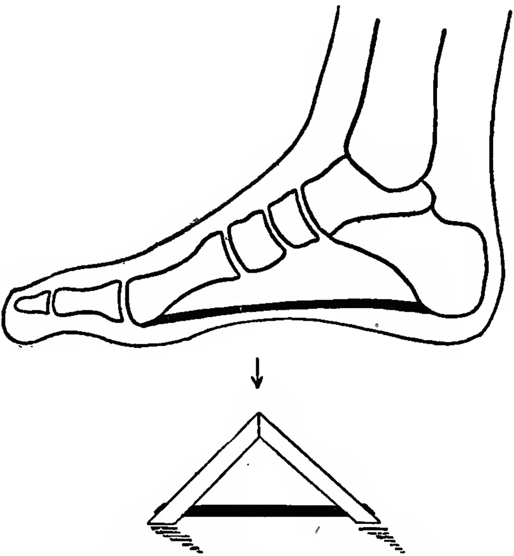

FIG. 29. The arch of the foot strengthened by a strong ligament, compared with a wooden arch strengthened by a steel "tie."

foot is in contact with the ground, the bones referred to form an arch which may be demonstrated by the ease with which a thin object such as a paper-knife can be pushed under the instep.

On the inner side of the foot the bones form a higher arch. As may be seen in Fig. 29, the front pillar of this arch is formed by the metatarsal bone of the great toe, the hind pillar by the os calcis, and the key-stone by the astragalus.

The diagram shows also two of the smaller tarsal bones which lie between the astragalus and the metatarsal.

When a heavy weight is borne upon an arch, the pillars of the arch naturally tend to be forced apart. In order to prevent this, builders frequently connect the bases of the pillars together by what is called a tie (Fig. 29). Such an arrangement can often be seen in steel bridges or in the steel arches of the roof of a railway station. This very device is found in the arch of the foot. Strong ligamentous ties stretch from the heads of the metatarsal bones (from the balls of the toes) back to the heel bone. The inner arch especially is further supported by additional ties formed by the long strong tendons which wind round the inner side of the ankle as round a pulley and run forward to the toes.

The inner arch is so high that even the skin of the inner side of the foot does not touch the ground in standing. This can be demonstrated by wetting the sole of the foot and walking across a wooden floor, when the footprint will be found to show a deficiency in its inner side.

The condition known as **flat-foot** is caused by the arch of the foot giving way. It occurs in those who have much standing, especially if they are not very strong. At an early stage standing becomes first fatiguing, and then acutely painful. The pain is due to the stretching of the ties of the arch. If taken in time this condition can usually be cured by diminishing the amount of standing, and by exercises designed to reproduce the arch, and to shorten and strengthen the ties.

Two other points may be noted here. The first is that the toes tend to spread apart when the foot is pressed upon the ground. The foot therefore is broader when we are standing than when we are sitting.

The second point is that in the normal foot the great toe and the inner border of the foot should lie in a straight line. Too frequently the great toe becomes permanently pressed against the other toes as the result of wearing badly shaped boots.

BONY LANDMARKS

Make yourself familiar with the following, most of which are mentioned in the description of the Skeleton and the Joints:

I. Head. Supra-orbital ridges
Zygoma (see Fig. 18)
External occipital protuberance (at back of head)
Mastoid process
Articulation of lower jaw
Angle of lower jaw
Symphysis menti (point of chin)

II. Spine. Seventh cervical spinous process
Count the dorsal and lumbar spinous processes
Coccyx

III. Chest. Supra-sternal notch
Ridge marking junction of manubrium with body of sternum. (This is opposite the *second* rib)
Ensiform cartilage
Ribs. (Count these. Note tips of floating ribs)

IV. Upper Limb. Scapula—superior and inferior angles, spine, acromion and coracoid processes
Clavicle. (Note curvatures)
Humerus—head, shaft, insertion of deltoid muscle, internal and external condyles
Ulna—olecranon process
Radius. (Feel rotation of head in a thin subject)
Metacarpals and phalanges

V. Lower Limb. Innominate bone—crest, anterior superior spine, ischial tuberosity (which supports the body in sitting), pubic symphysis (where the two bones join in front)
Femur—great trochanter, shaft, external and internal condyles
Patella
Tibia and Fibula (internal and external malleoli)
Os Calcis
Head of Astragalus, Scaphoid, base of first metatarsal (on inner side of foot)
Base of fifth metatarsal (on outer side of foot)
Study the arch of the foot carefully

CHAPTER IX

THE STRUCTURE OF THE SUPPORTING TISSUES

THE supporting structures of the body are connective tissue, cartilage, and bone.

Connective Tissue.—If a piece of fresh meat is teased out with needles it can be made out that the red muscle substance is bound up in bundles by means of a soft white shreddy material. This is connective tissue.

Connective tissue is not only found between the bundles of muscle fibre. It also forms a sheath round every individual muscle; it connects the skin with the structures lying underneath; it forms the various ligaments and tendons; and in short it forms a supporting framework and covering for every organ in the body.

If a little connective tissue is examined under the microscope it is seen to be composed of bundles of wavy fibres which are white in colour and non-elastic; of much more sharply defined yellow elastic fibres; and of small branching cells, the connective tissue corpuscles.

Fatty tissue consists of a basis of connective tissue and of very numerous cells, each of which contains a large globule of oil (Fig. 5).

Cartilage.—The cartilage which covers the joint end of a fresh bone can be cut into thin slices with a razor. If the thinnest possible section is examined under the microscope it will be found to consist of a clear substance—called the *matrix*—in

which cells (Fig. 5) are embedded at intervals. Many of the cells are arranged in groups of two or four. Cartilage of this kind with a clear or glassy matrix is termed *hyaline*, and is found not only covering the articular ends of bones, but also forming the cartilages of the ribs, the rings of the wind-pipe, and the firm parts of the larynx.

In the intervertebral discs the matrix is permeated by a feltwork of fibres, hence this material is called white fibrous cartilage.

In a few places, for example, in the cartilage of the ear, a network of yellow elastic fibres is present in the matrix. This form of cartilage is called yellow elastic cartilage.

Bone.—The bones in the prepared skeleton are not only dead bones. They are dry bones. In order to make out more clearly the structure of a fresh bone it is necessary to procure from the butcher the knuckle end of a marrow bone—that is to say, the joint end of a long bone.

Compare the thick glistening layer of articular cartilage in the fresh bone with the thin horny coating to which the cartilage has shrunk in the dry bone.

Notice also how the shaft of the fresh bone is enveloped in a sheath of connective tissue which can be scraped off with a knife. This is the **periosteum.** In it run numerous minute blood-vessels which convey nourishment to the bone.

Where the shaft of the bone is cut across observe the large central cavity filled with soft marrow.

Split the bone longitudinally and find out how far the marrow cavity runs. It will be found that the shaft of the bone is tubular in form, but that the extremities are solid.

Compare the bone forming the extremity with that forming the shaft. Notice that the former is open and spongy in texture and that the latter is very dense and compact. Spongy bone is termed *cancellous* and its structure of interlacing fibres of bone can be seen to better advantage in a dry bone after

the soft organic material which fills the interspaces of the fresh bone has been washed away or allowed to dry up.

A bone of the form which we are examining, which possesses a shaft and two extremities, is called a *long bone.* In all animals which possess long bones, the shafts of the bones have a tubular form. The mechanical advantage of this is that the strongest rod which can be made out of a given weight of material is a tube. If our bones were solid throughout and retained their present thickness they would no doubt be stronger than they are at present but they would also be very much heavier. On the other hand, if, without becoming heavier, they were compressed into solid rods they would be so weak that broken limbs would be the rule rather than the exception. The great strength of tubes is taken advantage of in the construction of such articles as steel pillars, bicycles, and tubular bridges. The modern bicycle is a marvel of combined lightness and strength as compared with the old velocipede, which required a strong man to lift it.

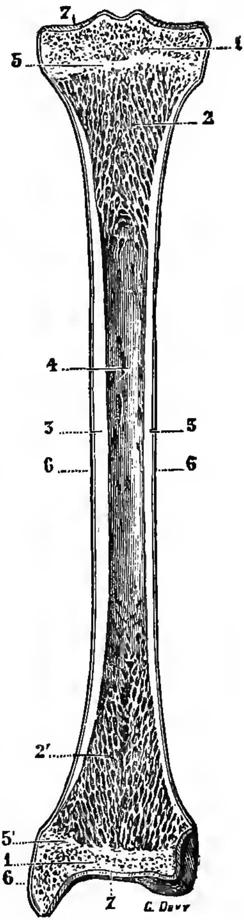

FIG. 30. Shin bone (tibia) sawn in two along its length. 2. Struts and stays of spongy bone supporting 7, the upper and lower articular surfaces. 3. Compact bone forming the shaft. 4. Marrow cavity. 6. Periosteum.

The *cancellous tissue* of the bone, irregularly spongy although it appears at first sight, is in reality built up on mechanical principles. The numerous

strands and fibres and spicules of bone of which it is composed are arranged in a quite definite fashion so as to bear the various pressures and strains to which the bone is subject. The more minutely the structure of a bone is examined the more we find to admire in the wonderful perfection and beauty of its mechanism.

The Various Forms of Bones.—A **long** bone has been defined as a bone with a shaft and two extremities. The term long applies to form rather than to absolute length. The phalanges of the fingers and toes, the metacarpal and metatarsal bones, are long bones in this sense just as much as the humerus, the femur, or the tibia.

The other varieties of bones are—

Short bones, like those of the wrist or ankle. These are formed of compact bone at the surface, of cancellous bone internally. They have no cavity.

Flat bones, like those of the roof of the skull.

Irregular bones, like the vertebræ.

CHEMICAL COMPOSITION OF BONE

Some of the principal facts concerning the chemical composition of bone can be made out by a few simple experiments.

1. Weigh a small fresh long bone such as the thigh bone of a rabbit, and leave it for a few days in dilute hydrochloric acid (1 in 7). In a variable time the bone will be found to have become quite soft and flexible. Wash it in fresh water, dry it on blotting-paper, and weigh it. It will be found to have lost weight considerably. This is due to the mineral constituents having been dissolved out. These may be recovered by evaporating the acid.

2. Procure from the butcher some pieces of fresh bone and boil them for some time in a little water—just enough to cover them. Pour off the fluid and set it aside. When it cools it should set into a jelly owing to the presence of gelatine extracted from the bones.

3. Weigh another small piece of fresh bone, put it in an iron spoon, and place it in a red-hot fire. At first it turns black from charring, and then it gradually becomes white. Now remove it from the fire and let it cool. Weigh the crumbling remains of the bone. About one-third of the original weight will be found to have been lost. Crumble up the fragments and cover them with hydrochloric acid. They will dissolve.

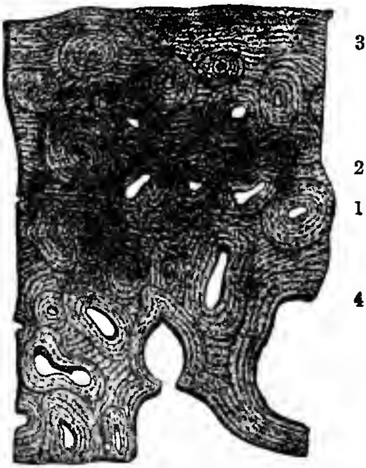

FIG. 31. Cross-section of a bone, magnified. The numbers indicate the arrangement of the bone in layers: 1, round the Haversian canals; 2, between them; 3, at the surface of the bone; and 4, next the central cavity.

These experiments teach us that bone is formed of a combination of *organic* and *mineral* matter. When the mineral salts are removed by means of an acid the bone retains its original shape. The organic basis of the bone is composed of white fibrous tissue which yields gelatine on boiling. The organic matter in the bone amounts to about 33 per cent. of the total; the mineral salts to about 67 per cent. The percentage of salts is relatively less in young animals and greater in old ones.

The Microscopic Structure of Bone.—When thin sections of compact bone are examined under the microscope it is found that there run through the bone minute channels (the

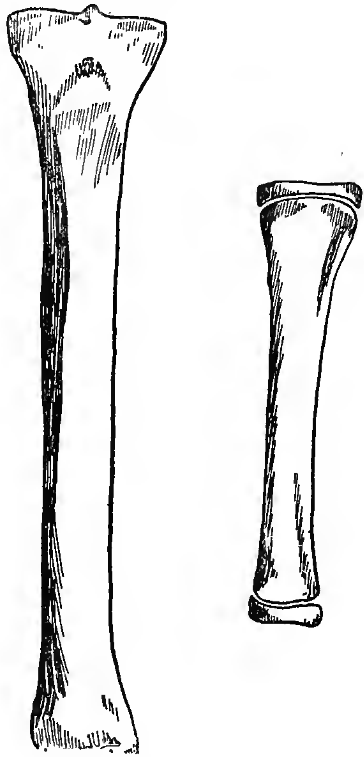

FIG. 32. Shin bone of adult, and of child. In the latter the epiphyses are distinct from the shaft.

Haversian canals), each surrounded by concentric rings. These rings are marked out by minute spaces, the lacunæ. In a section of softened bone there can be seen in these lacunæ the bone-cells. The cells are branched and their

branches extend into little channels, the canaliculi. In the shafts of the long bones the Haversian canals run parallel to the shaft. Minute blood-vessels traverse the Haversian canals, and from them lymph exudes into the lacunæ and canaliculi carrying nourishment to all parts of the bone. In cancellous bone the spaces between the bony spicules are filled with marrow.

The Growth of Bone.—The bones of young children differ in many respects from those of adults. They contain, as has already been stated, a relatively small percentage of mineral matter. As a result of this they are less brittle, and if they are broken, instead of cracking right across they often break like a green stick without separating into two fragments. They are also more vascular, they have a more abundant supply of blood-vessels than the bones of grown people. This abundant blood-supply is required for the growth of the bone.

Growth takes place in two ways.—The thick vascular periosteum is continually forming layers of bone which bring about a steady increase in thickness. Growth in length takes place, not at the extremities, but between the extremities and the shaft. In this position there may be found running right across the bone a layer of cartilage. The cells in this cartilage undergo very active division, but instead of the cartilage becoming thicker, lime salts are continually deposited and fresh bone is built up. This cartilage is called the epiphyseal cartilage. As long as it persists the bone grows in length, but in time the deposit of lime salts and the formation of fresh bone become more active than the growth of the cartilage, and finally the entire cartilage is replaced by bone. The separate extremity of the bone, called the *epiphysis*, thus becomes fused with the shaft.

PECULIARITIES OF THE SKELETON OF THE CHILD

The principal peculiarities of the skeleton of the child are three-fold :

1. The *proportions of the skeleton* must obviously differ in

childhood and maturity as do those of the body generally (*see* page 17).

2. The younger the child the larger *the proportion of cartilage and fibrous tissue* in the bones.

In the spine, for example, there is comparatively little true bone at the time of birth. The bodies of the vertebræ consist

FIG. 33. Skiagram of child's hand. Note that the ends (epiphyses) of the radius and ulna and of the phalanges and metacarpal bones are not yet fused with their shafts. Note, also, the imperfect ossification of the small bones of the wrist.

of masses of cartilage each with a central kernel of bone. For this reason the spine is extremely flexible in infancy. The flexibility gradually lessens as the bones grow firmer.

The wrist and ankle bones, again, are for a considerable period represented by blocks of cartilage. Even in a child of seven or eight years of age the nucleus of bone is just beginning to form in some of these pieces of cartilage.

3. Throughout the skeleton we find *provision made for growth.*

The bones of the skull are not firmly dovetailed together,

and in infancy considerable gaps exist in places between their edges. The largest of these is between the frontal bone and the parietals. This is the anterior fontanelle, often popularly called "the opening of the head." There is not really an opening, however, as the gap between the bones is filled by a

FIG. 34. Skiagram of child's foot. Compare with Fig. 33 and Fig. 29.

membrane. During life the pulsations of the brain, that is to say, of the vessels which carry blood to the brain, can readily be seen on the top of an infant's head. The fontanelle gradually diminishes in size and closes at about the age ot eighteen months.

The flat bones do not have epiphyses but grow at their edges, while the periosteum which covers them brings about a growth in thickness.

The mode of growth of the long bones has been described.

The *epiphyses* of these bones, as the extremities are called, so long as they remain separate, become united by bone to their respective shafts chiefly between the ages of seventeen and twenty-five.

The comparative softness of the bones of children and the fact that a process of active growth is at work are of importance in relation to the deformities which are so often acquired in early life. Not only does the softness of the bones allow them to become distorted when subjected to abnormal pressure (*e.g.*, in the habitual assumption of wrong postures), but the growth processes adapt themselves to the strains and stresses which the new conditions involve. For example, if a bone has been bent by a child's weight, it may gradually grow straight again if the child's weight is kept off it for a time. But if this is not done, nature does the next best thing by rendering the crooked bone unusually thick and strong.

CHAPTER X

THE MUSCLES

THE mechanical work of the body is effected by means of the muscles. Muscle forms more than one-third of the entire weight of the body.

Varieties of Muscle.—The muscle present in the walls of the stomach and intestine is strikingly different from that which forms the flesh of the body, and which is attached to different parts of the skeleton. Hence we recognise two kinds of muscle—visceral and skeletal.

(*a*) **Visceral or involuntary** muscle is found in the stomach, intestine, bladder, arteries, veins, and some other places. It is composed of long spindle-shaped cells, each with a nucleus in its interior. It is sometimes called unstriped muscle fibre because, unlike the other variety, it does not show transverse stripes under the microscope. The term involuntary is not strictly accurate because some unstriped muscle (that of the bladder) is under the control of the will to a considerable extent.

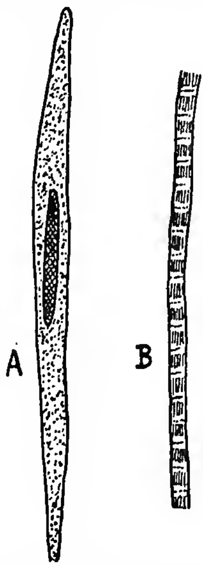

FIG. 35. Muscle, highly magnified. A. Unstriped muscle. B. Part of a striped muscle fibre.

(*b*) **Skeletal or voluntary** muscle is composed of very fine fibres arranged in bundles. A single fibre may be 2 inches in length, but is only about $\frac{1}{500}$

inch thick. These fibres are derived from cells, but as a number of nuclei are found in each fibre, we must regard the fibre as representing several cells whose protoplasm has not divided. Microscopically these fibres are marked by alternate dark and light stripes which cross them transversely.

The fibres of a muscle are grouped in bundles between which is connective tissue. On the surface of the muscle the connective tissue forms a sheath around the entire muscle. Every muscle is richly supplied with blood-vessels which run between the fibres. A nerve with both sensory and motor fibres passes into each muscle. Every fibre of the muscle receives a minute branch from one of the nerve fibres.

The Appearance of a Skeletal Muscle.—A muscle usually consists of a fleshy belly whose ends are attached to two bones. The muscle may be attached directly to the bone, but as a rule the connection is made at one or both ends by means of a strong cord called a tendon or sinew. On the back of the hand one can easily make out the tendons which pass to the fingers from the muscles of the forearm.

The Properties of Muscle.—The muscles of a frog are very convenient for study because they remain alive for a considerable time after the frog has been killed. In a muscle freshly removed from the body three properties are easily made out. These are:

(*a*) *Extensibility.*—If the muscle is suspended by one end and a small weight attached to the other, the muscle will be stretched.

(*b*) *Elasticity.*—If the weight is removed the muscle will shorten again.

(*c*) *Contractility.*—If the muscle is sharply pinched, or touched with a hot wire, or if an electric shock is passed into it, it will contract strongly, becoming shorter and thicker for a moment, and then returning to its original condition.

This last property is the most important characteristic or muscle. It is by its contractility that muscle does its work. Muscles do not, however, contract spontaneously. Within the body, as outside of it, muscles contract in response to a stimulus. The normal stimulus is the nerve current which passes down the nerve from the brain or spinal cord.

When a muscle contracts it necessarily pulls upon the structures to which it is attached, and tends therefore to bring them nearer together. As a general rule, a muscle stretches from one bone to another across a joint, or in some cases across more joints than one. These joints allow movement to take place when the muscle contracts. The attachment of the muscle to the more movable bone is called the *insertion* of the muscle. The more fixed attachment is called the *origin.* The particular movement that occurs is called the *action* of the muscle. A muscle need not necessarily be inserted into a bone. The movements of the face, for example, are due to muscles which arise from the bones of the face, and are inserted beneath the skin.

The Chemistry of Muscle.—About three-fourths of muscle is composed of water. The rest is made up largely of proteins and salts. The juice which can be squeezed out of fresh muscle sets into a jelly. This jelly contains a protein called myosin. The stiffness which supervenes after death, and which is called *rigor mortis*, is due to this change. The clotting of blood and the curdling of milk are similar processes. Glycogen is present in resting muscle. It diminishes during activity, being used for the nourishment of the muscle.

When a muscle contracts chemical changes take place. Certain very complex substances within the muscle break down into simpler compounds. The reaction of the muscle, which was previously alkaline, becomes acid, and a great deal of carbonic acid is formed and carried away by the blood. The energy which is set free by these chemical changes is converted partly into mechanical work and partly into heat. The process is

analogous to the explosion of gunpowder, when part of the energy liberated drives the bullet, and part warms the barrel of the gun. A contracting muscle liberates also a minute quantity of electricity. It is a curious fact that the discharging organs of electric fishes, such as the electric eels of South America, are derived from much modified muscles. These organs, which are used as a means of defence, are able to give a very strong and painful shock.

Modes of Action of Muscle.—Muscle is sometimes described as having three modes of action, viz: (*a*) *Concentric*—in over-

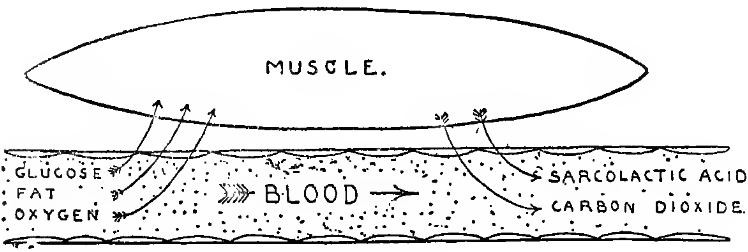

FIG. 36 Diagram showing the chemical changes which take place in muscle, the blood bringing nourishment and carrying away waste substances. (N.B. The acids entering the blood combine at once with other substances.)

coming resistance, as in lifting a weight. (*b*) *Eccentric*—in giving way to resistance, as in lowering a weight. (*c*) *Static*—in contracting or stiffening without giving rise to movement.

These are, however, simply varieties of the one fundamental mode of action—namely, contraction. All our movements are brought about by the contraction of muscles, which, in contracting, pull upon the parts to which they are attached.

Muscles always act by pulling. They never push. If I raise a weight in my hand and lower it again, the muscles first pull sufficiently strongly to overcome the attraction of gravity, then insufficiently strongly. In static contraction the muscles pull just strongly enough to balance the resistance, it may be of gravity, it may be of muscles pulling in a contrary direction.

The Action of Particular Muscles can easily be studied in the living body.

The Muscles of the Head and Neck.—Slightly separate your teeth and place your forefinger over the hinder part of the cheek. Now clench your teeth. You will feel something swell up and become firm under the finger. This is the **masseter** muscle. It is attached above to a ridge of bone which you can feel in front of the ear. Below it is attached to the lower jaw. Its action is to draw the lower jaw up; in other words, to close the mouth. As closing the mouth is effected by moving the lower jaw, the lower end of the muscle is its insertion, the upper is its origin.

Now place your finger in the little hollow at the lower part of the neck. You will feel the top of the breast bone and the inner ends of the two collar bones. You will feel also two little strings running up the neck. Now turn the head strongly to the right and you will feel the left-hand string spring up and become taut. Follow it up the neck and you will have little difficulty in making out that the string is a tendon belonging to a muscle which can be traced up the side of the neck to the mastoid process behind the ear. This muscle is called the **sterno-mastoid** muscle because it stretches from the sternum to the mastoid process. It lies just under the skin, and its action, which is to turn the head to the opposite side, can easily be seen in thin persons. The sterno-mastoid muscles have also another action. If the head is fixed, the two sterno-mastoid muscles, by contracting together, assist in raising the front of the chest, as in drawing a deep breath.

The Muscles of the Arm.—Now examine the shoulder while the arm is lying by the side. You can easily make out the sharp tip of the shoulder formed by the projecting spine of the scapula. Just below this is a soft fleshy mass which becomes hard and firm the moment the arm is raised the least from the side. This is the **deltoid** muscle. The origin of this muscle is from the shoulder-blade and collar-bone above. Its insertion is into the humerus below. Its action is to pull upon the humerus, and so to abduct the arm. By contracting powerfully it can raise the arm from the side until it is stretched out horizontally.

In the arm we can make out very well a point of great importance. I have said that muscles always act by pulling. We might, therefore, expect that, if a muscle can pull a bone in one direction there ought to be another muscle to pull it back again. This is actually the case. For example, we find in front of the arm the well-known **biceps** muscle, which stretches from the shoulder-blade to the radius, and which by contracting bends the arm at the elbow. To straighten the arm again the **triceps** muscle, which lies at the back, contracts. This powerful muscle is inserted into the tip of the ulna at the elbow, and by its pull upon the ulna the straightening of the arm is effected.

What happens to the triceps when the arm is bent? Obviously it must be stretched. While stretched, the triceps remains taut, partly because it is elastic, and partly, also, because it maintains a very slight degree of contraction or tone. This *tone* is very important because it keeps the muscle ready to contract instantly, and so a movement can be effected without loss of time.

If you will now look at the skeleton you will see on the radius below its head a little rough tubercle. It is to this that the tendon of the biceps is attached. Now turn the fore-

arm of the skeleton into the prone position, and notice how the tubercle on the radius is twisted round to the back. What, then, becomes of the tendon of the biceps when the forearm is pronated? Obviously it must be twisted round the radius. If the biceps were now to contract it would necessarily tend to untwist the radius, that is to say, to bring about supination of the forearm. This, indeed, is part of the action of the biceps. When the forearm is pronated the action of the biceps is, first, supination; and secondly, flexion, of the forearm. The action is easily remembered because it is that which is carried out in drawing a cork.

In the forearm, also, we find opposing groups of muscles. The muscles in front of the fleshy part of the forearm are the **flexors** of the wrist and fingers, and the **pronators** of the radius. The muscles at the back are their antagonists, the **extensors** and the **supinators.**

The powerful grasp of the hand is due to the fact that it is effected by the large muscles of the forearm. Separation of the fingers is due to the action of small muscles in the hand, and is obviously a very weak movement. The movements of the thumb are guided by the small muscles in the ball of the thumb, but the chief power of these movements is due to the special thumb muscles in the forearm.

The Muscles connecting the Arm with the Trunk.—The borders of the armpit are formed by two powerful muscles. The front border is formed by the **great pectoral**, or breast muscle, which stretches from the sternum and collar bone to the humerus. When the arm is raised, this muscle draws it downwards and forwards. In drawing the arm down it is assisted by the muscle in the hinder border of the armpit, the **latissimus dorsi.** This muscle arises from the hip bone and lumbar vertebræ and is inserted into the humerus. It pulls the humerus downwards and backwards. Both of these muscles are called into play in such exercises as pulling upon a bell-rope or climbing by the arms. The

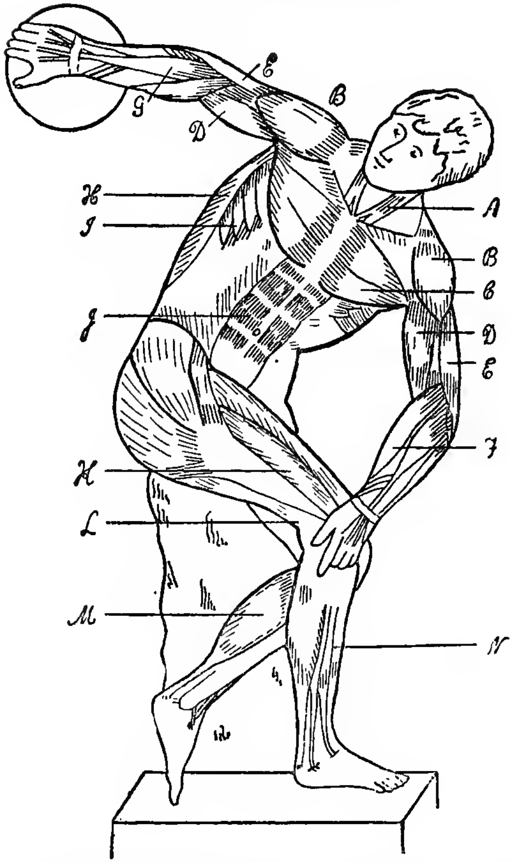

FIG. 37. Superficial muscles. A. Sterno-mastoid. B. Deltoid. C. Pectoralis major. D. Biceps. E. Triceps. F. Supinator of forearm. G. Extensors of fingers. H. Latissimus dorsi. I. Serratus magnus. J. Rectus abdominis. K. Flexors of thigh (extensors of knee). L. Hamstring muscles. M. Calf muscles (extensors of foot). N. Flexors of foot (extensors of toes).

latissimus dorsi is powerfully exerted in rowing, as, when the arm is stretched forward, its action is to draw it back.

Two other muscles which act on the shoulder must be

mentioned. One is the **serratus magnus**, which stretches rom the side of the chest to the scapula, and draws the shoulder forward. It is described in the chapter on respiration. The other is the **trapezius**, which arises from the skull and the vertebræ of the neck and back, and is inserted into the angle between the collar bone and the shoulder blade. It is a triangular muscle, but forms a trapezium with its fellow of the opposite side. The trapezius muscles draw the shoulders back. If their upper fibres act more powerfully they assist in raising the shoulders, while their lower fibres tend to draw them down again.

The Muscles of the Trunk.—In the back there are numerous muscles arranged in several layers. The most important is the **erector spinæ**, which stretches right up the whole length of the spine to the back of the head, giving off slips to the various vertebræ. It assists in maintaining the erect posture. Powerful contractions tend first to straighten the spine, then to bend it backwards.

The wall of the abdomen is strengthened by several powerful muscles, which also assist in maintaining the erect posture, and on occasion act as respiratory muscles, when a powerful expiration is called for.

The Muscles of the Lower Limbs.—The numerous muscles of the thigh may be divided into three groups. In front are the muscles which *flex* the thigh on the abdomen, and those which, by pulling upon the patella (*see* p. 71), *extend* the leg upon the thigh. Behind are the opponents of these muscles, those, namely, which *extend* the thigh and *flex* the leg. The cord-like tendons of the flexors of the leg can be felt under the skin behind the knee. Hence the popular name "hamstrings" applied to these muscles. On the inner side of the thigh are the *adductors*, by which the legs are drawn together. These muscles become very strong in riders.

The muscles at the back of the thigh have another action

to the pelvis, they prevent us from falling when we stoop forward, and their more powerful contraction raises the body

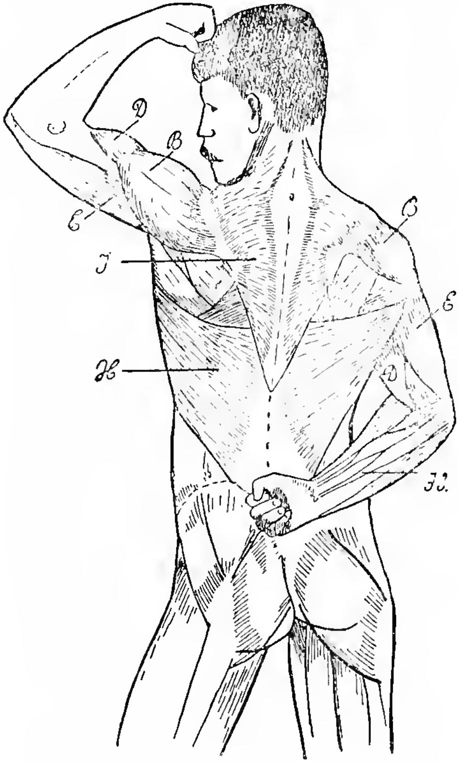

Fig. 38. Muscles of back. T. Trapezius. Fl. Flexors of fingers. Other letters as in Fig. 37.

again. In this action they are assisted by the muscles of the buttocks, which also have another action, namely, *rotating* the femur outwards. You can easily make out that when you turn out your toes, the movement takes place at the hip joint.

The great mass of muscle in the calf ends in the **tendo**

Achillis, which is inserted into the os calcis, and can be felt just above the heel. This muscle is particularly used in rising on tip-toe, and is therefore called into play in walking and running.

In the leg there are also muscles whose long tendons stretch

FIG 39. Muscles of back as in Fig. 38.

to the toes. Those in front of the leg *flex* the foot and *extend* the toes, while those behind have the opposite actions.

The Erect Posture.—In the erect posture the muscles in front of the leg and the calf muscles keep the leg from bending at the ankle joint. The body cannot fall forward at the knee owing to the strong ligaments which keep the knee from bending the wrong way. The muscles of the thigh, whose strong tendon passes in front of the knee, keep the body from falling back at that joint.

At the hip the pelvis is balanced by the muscles which

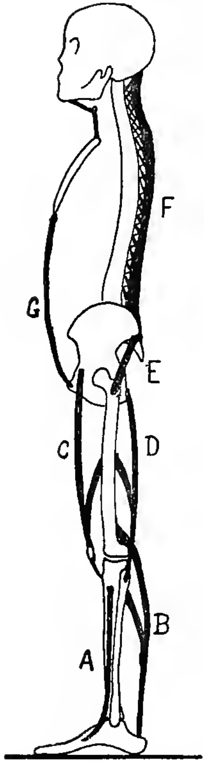

FIG. 40. Muscles which maintain the erect posture (after Huxley). A. Muscles of front of leg. B. Calf muscles. C. Muscles of front of thigh. D. Muscles of back of thigh. E. Muscles connecting pelvis with femur. F. Muscles of back. G. Muscles of abdomen.

stretch to the front and back of the thigh, but very little muscular exertion is necessary, for the centre of gravity of the trunk lies slightly behind the centre of the hip joints, while a strong ligament in front of these joints prevents the body from falling back.

The spine is kept erect by the strong muscles of the trunk, while the muscles of the back of the neck keep the head from dropping forward.

The necessary contraction of these muscles is maintained by the nervous system, and if the nervous control is removed, as occurs, for example, in a faint, the body falls all in a heap.

Common Faults in Standing.—One of the most common faults in standing is to allow the pelvis to tilt forward. This tends to bring the centre of gravity in front of the hip joints. To prevent this the upper part of the trunk is thrown back sufficiently to compensate for the forward tilt of the pelvis. The result of this double movement is that the lumbar curve is increased, and the person becomes hollow-backed.

Another fault is to droop one side of the pelvis by bending one knee. This attitude produces a lateral curvature of the spine.

In whatever position we stand, it is, of course, necessary that the centre of gravity should fall within the base of support. This explains why a man leans backward when he is carrying a heavy weight in his arms,

and bends forward if he carries it on his back. When a heavy weight is carried on one arm a lateral curve of the spine is produced, and if this position is assumed habitually definite deformity may result. There is a distinct danger of this occurring if children have to carry heavy bundles of books under their arm to and from school daily.

Walking.—In walking one leg is slightly bent at the knee by the contraction of the hamstring muscles, so as to allow the foot to clear the ground. This leg is swung forward by the muscles in front of the thigh. The body is raised on the toes of the other leg by the action of the calf muscles. At the same time the body is thrown forward, but is prevented from falling by the foot of the swinging leg, which comes to the ground and receives the weight of the body. In easy walking on a smooth road comparatively little muscular exertion is necessary, for each leg in turn swings forward like a pendulum. A long-legged man naturally has a slower step than a short-legged man for the same reason that a long pendulum swings more slowly than a short one.

Running.—In running both feet are momentarily off the ground during each step, and consequently more powerful as well as quicker contractions of the muscles are necessary to propel the body forward. In this the calf muscles are assisted by the powerful action of the extensor muscles of the thigh, which straighten the bent knee of the forward leg.

The General Effects of Physical Exercise.—Considering the large bulk of muscle in the body, it is not surprising that a considerable amount of exercise is essential to good health.

Regular physical exercise produces a marked effect on the muscles themselves, which increase in size and become stronger and more capable. The bones to which they are attached also grow firmer and stronger.

Muscular contraction is associated with a quickened blood-flow and increased rapidity of the heart's action. This quickened blood-flow rapidly distributes the heat which results

from the muscular contraction, so that the body becomes warm. The skin is flushed with blood, and the sweat-glands secrete more freely. Active exercise very quickly produces sensible perspiration.

During exercise oxygen is removed more quickly from the blood, and a greater amount of carbonic acid is added to it. Respiration is therefore quickened and deepened, in order that fresh oxygen may be supplied to the blood, and that the carbonic acid may be removed.

Physical exercise also promotes digestion. During exertion the body's stores of nutritive material are depleted, and a certain amount of tissue waste takes place. Appetite is the call of Nature for fresh material to replace what has been lost. Moreover, the active circulation which exercise promotes involves the digestive organs and aids the secretion of active digestive juices. The abdominal organs are also pressed upon intermittently by the contractions of the powerful abdominal muscles, and thus undergo a kind of massage which improves the tone of the muscle in the walls of the stomach and intestine, and assists the circulation of the blood in these organs and in the liver.

On the nervous system the effect of exercise is very important. A little active exercise affords relief and refreshment during mental work, by quickening the circulation and supplying the brain with a rapid stream of well oxygenated blood. Severe muscular exercise, on the other hand, loads the blood with fatigue products, and thus interferes with cerebral activity and induces drowsiness.

But the principal effect of exercise on the nervous system depends upon the fact that muscular activity is entirely under the control of the nerve centres in the brain and spinal cord. Whenever we learn to use our muscles in a new way, as in learning to skate, to bicycle, to knit a stocking, or use a typewriter, we are, in point of fact, educating not so much our

muscles as our nervous systems. In all such complicated movements numerous nerve centres are called into play, and taught to act in association with one another.

CHAPTER XI

THE CIRCULATION OF THE BLOOD

ONE of the greatest physiological discoveries was made by an Englishman, John Harvey, in the beginning of the seventeenth century. This was the circulation of the blood.

The circulation of the blood is effected by the heart and blood-vessels.

The Blood-vessels.—Blood-vessels are of several kinds.

a. **Arteries** are vessels which carry blood away from the heart. They are tubular structures whose walls are elastic and contain unstriped muscle fibre. The calibre of an artery can be increased or diminished by the relaxation or contraction of the muscle fibre in its wall. The pulse which you can feel at your wrist is due to waves of blood passing through the radial artery. A similar pulse can be felt in many other places, for instance, in the carotid artery in the neck.

b. **Veins** are vessels which convey blood *to* the heart. Their walls are thinner than those of arteries. No pulse can be felt in them because the blood flows through them in a steady stream. Many veins lie just under the skin, and are made visible by their bluish colour. Observe how the veins in your arm become more conspicuous if you allow it to hang down, and much less conspicuous if you stretch it up. This obviously results from the flow of blood in the veins being against gravity in one case, and with gravity in the other.

Now find a large vein in the arm and stroke it firmly up the arm. Observe that you can easily empty the vein, which becomes quite inconspicuous as the finger passes over it.

Again, stroke the vein downwards towards the hand. The vein will swell up and you will probably be able to make out little knots or thickenings upon it. These are due to the presence of little valves like pockets of thin membrane within the vein. The valves allow the blood to flow towards the heart, but offer an obstruction to its flowing back. Sometimes, especially when people have too much standing, the valves get damaged and fail to act properly. Then the vein becomes dilated or *varicose*.

FIG. 41. Vein cut open to show the valves.

Valves are not present in the arteries.

c. **Capillaries** are minute vessels which connect the terminations of the arteries with the beginnings of the veins. Arteries as they pass through the body divide into smaller and smaller branches. The smallest arteries end in a network of capillaries. The pink colour of your nails and the red of your lips are alike due to the blood flowing through a capillary network. Press upon your nail and observe the white area which results from the blood being expelled from the capillaries.

In this capillary network minute veins arise, and these unite together to form larger veins.

The Heart.—The heart is a muscular organ. It is hollow, being divided into four chambers called the right auricle and ventricle, and the left auricle and ventricle. There is an opening between the right auricle and the right ventricle, and another between the left auricle and the left ventricle. There is no opening between the chambers of the right side of the heart and those of the left.

When the heart muscle relaxes, the size of the chambers increases and blood flows into the heart from the great veins. When the muscle contracts the blood is forced out of the

heart again. It is not forced back into the veins but onward into the arteries.

There is one great difference between the right side of the heart and the left. *The right side of the heart receives the impure blood from all parts of the body, and sends it on to the lungs, where it is purified.*

The left side of the heart receives the pure blood from the lungs and sends it to all parts of the body.

To understand this process better it will be necessary to examine the structure of the heart in greater detail.

The Position of the Heart.—The heart lies in the thorax between the two lungs. It is placed behind the sternum, but extends slightly to the right and considerably to the left of that bone. In fact it extends about as far as the left nipple. The "beat" of the heart can be felt under the fifth rib on the eft side, and this corresponds to the lowest part of the heart.

The Pericardium.—The heart is enveloped in a tough membrane called the pericardium. The interior of this membrane is very smooth and shiny, and so, also, is the surface of the heart. In this bag is a small quantity of fluid. The smoothness of the membrane and the presence of the fluid facilitate the movements of the heart, just as the synovial membrane and the synovial fluid facilitate the movements of a joint.

The Structure of the Heart.—Procure a sheep's heart from a butcher and examine it. It is conical in form. The apex is the lower end. The upper end or base is broad, and upon it may be seen the remains of large blood-vessels which have been cut across. You can distinguish the front of the heart by the fact that it is not so flat as the back, and by the presence of a groove filled with fat which runs obliquely down it. On the back of the heart there is a corresponding, but much less conspicuous, groove. These grooves mark the division of the heart into a right and a left side. In fact they correspond to the partition between the right and left ventricles.

At the base of the heart you will see a flat ear-like structure

on each side. These are parts of the right and left auricles. You can easily feel that the walls of the auricles are quite thin, and also that the wall of the right ventricle is not so thick and firm as that of the left.

To see the chambers of the heart properly it is necessary to open them. Begin with the right auricle, but before opening

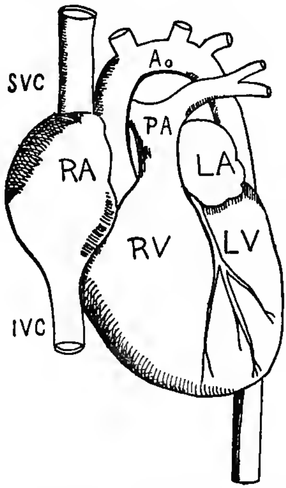

FIG. 42. The heart. SVC, IVC. Superior and inferior vena cava conveying blood to RA, right auricle. RV. Right ventricle giving off PA, pulmonary artery, which divides into branches for the lungs. LA. Left auricle. LV. Left ventricle, from which comes Ao, the aorta.

it, look for the two large veins which carry blood to the auricle. One of these is the *superior vena cava*, and it brings all the blood from the head and fore-limbs. The other is the *inferior vena cava* and it brings the blood from the rest of the body. These veins may have been cut off quite short. If so you will easily find the apertures corresponding to them.

Now cut the auricle open from the one vena cava to the other, and push your finger into it.

You will find that you can push it right through the auricle into the right ventricle.

Next, withdraw your finger, and wash away the clots of blood from the interior of the auricle. Hold up the heart by the auricle, and, keeping it as widely open as possible, get some one to pour water through the auricle into the ventricle. If the wall of the ventricle is now pressed gently you may see

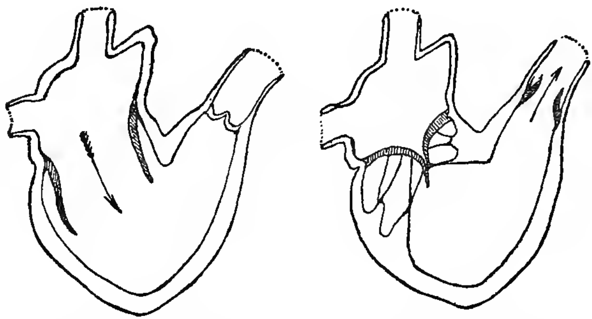

FIG. 43. Diagram of right side of heart. 1. The auricle drives the blood into the ventricle through the open tricuspid valve. 2. The ventricle contracts, the tricuspid valve closes, and the blood is driven on into the pulmonary artery. The same diagram will serve for the left side of the heart.

three little flaps of a whitish colour rise up and close the opening between the auricle and ventricle. These constitute the **tricuspid valve**. To see this valve better open the right ventricle by cutting parallel to the groove between the ventricles and about half an inch from it. When you have opened into the ventricle pass a penholder into it and push it gently towards the base of the heart, keeping it parallel to the groove. By so doing you will push the penholder out through one of the great blood-vessels which have been cut

across at the base of the heart. This is the pulmonary artery. Continue the cut so as to open up the artery. You will now be able to see the cavity of the ventricle clearly. Find the tricuspid valve and notice the delicate threads which extend from the edges of the flaps or cusps of the valve to the wall of the ventricle. These are called the *chordæ tendineæ.* The projections from the wall of the ventricle to which they are attached are called *musculi papillares.*

When blood flows from the auricle into the ventricle the tricuspid valve offers no resistance to its passage, but when the ventricle is full the cusps of the valve float up and will not allow the blood to flow back into the auricle. The chordæ tendineæ prevent the cusps from being forced back too far.

Now examine the pulmonary artery which you have split open. This is the artery which carries the blood to the lungs. Just where it leaves the ventricle there are three very delicate pockets of thin membrane. These are the **pulmonary semi-lunar valves.** When blood is driven from the ventricle into the artery these valves lie flat and do not obstruct its flow, but as soon as the ventricle has ceased contracting the pockets fill with blood, and so bulge out and block the passage, thus preventing the blood from flowing back to the ventricle.

The structure of the left side of the heart closely resembles that of the right. The veins which open into the left auricle come from the lungs and are called pulmonary veins. There are two of these in the sheep, four in man.

The valve which prevents blood from flowing back from the left ventricle into the left auricle resembles the tricuspid valve in structure, but it has only two cusps and is called the **mitral valve,** from a fancied resemblance to a bishop's mitre.

From the left ventricle as from the right there comes one large artery. This is called the **aorta,** and through it passes all the blood which is to be distributed to the various parts

of the body including the substance of the heart itself. The arteries of the heart are called the *coronary arteries*. The **semi-lunar valves** of the aorta are precisely similar to those of the pulmonary artery. Instead of splitting the aorta up, it is a good plan to cut it across about half an inch from its origin (if the butcher has left more of it than that) and pour water into it. The valves will close and prevent the water passing into the ventricle.

The cavities of the heart are lined by a thin smooth membrane called the *endocardium*. The valves of the heart are practically folds of endocardium. They contain no muscle in their substance.

Notice the great thickness of the left ventricle as compared with the right. The difference is due to the difference in the amount of work which the ventricles have to perform. It requires much less force to send blood to the lungs than to send it all over the body.

A Beat of the Heart.—During each beat of the heart a number of different events take place. Corresponding events occur simultaneously on the two sides of the heart. The two auricles fill with blood, the right from the venæ cavæ, the left from the lungs. They then contract and drive the blood on into their respective ventricles. As soon as the ventricles are filled they also contract. The first effect of the contraction of the ventricles is to force together the cusps of the tricuspid and of the mitral valves. Thus the doors into the auricles are closed. The pulmonary and aortic valves at this time are also closed, but the increasing pressure of the blood in the ventricles forces them open, and the ventricles then empty themselves into the pulmonary artery and the aorta respectively. As the ventricles contract, the apex of the heart is pressed against the wall of the chest, and this causes the beat which we are able to feel.

When the ventricles have sent their contents into the arteries they begin to relax. This tends to suck the blood

back again, but immediately the little pockets of the pulmonary and aortic valves fill, and block up the arterial orifices thus preventing any back-flow.

The Sounds of the Heart.—By placing your ear against a person's chest just over the heart you will be able to hear two sounds, which follow one another rapidly and are succeeded by a slightly longer pause. The first sound is dull, the second is sharp. They may be compared not inaptly to the syllables, lūb, dŭp. The first sound is caused chiefly by the closure of the tricuspid and mitral valves, the second by the closure of the pulmonary and aortic valves. While listening to the sounds feel the beat of the heart and try to make out whether the beat corresponds in time to either of the sounds.

The Course of the Circulation.—The general course of the circulation has been described sufficiently, but one or two of the more important arteries may be mentioned. The first branches given off by the aorta are two small arteries (the *coronary* arteries) which are distributed to—that is to say, they divide and subdivide into branches in—the substance of the heart itself. The aorta then forms a curve called its arch, from which three large branches are given off. The first of these (the *innominate* artery) immediately divides into two—the right *subclavian*, which carries most of the blood to the right arm, and the right *carotid*, which runs up the right side of the neck and head. The second branch is the left carotid, and the third is the left *subclavian.*

The aorta then curves down by the side of the spine and runs down through the thorax into the abdomen. On its way it gives off branches to the walls of the chest and abdomen, and to the stomach, intestines, liver, kidneys, and other viscera. Finally it divides into two great vessels, the *common iliac* arteries. Each of these divides into an *internal iliac* which gives off branches to the organs in the pelvis and to the buttock, and an *external iliac* which passes to the front of the thigh where it becomes known as the *femoral* artery.

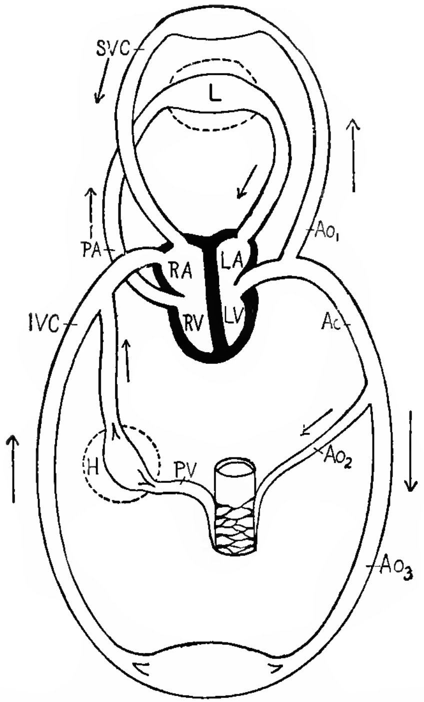

FIG. 44. Scheme of circulation. All the vessels which contain pure blood have been drawn to the right of the diagram; impure, to the left. From the lungs (L) the blood flows to the left auricle (LA), the left ventricle (LV), the aorta (Ao), and thence to the head and arms Ao_1), the viscera (Ao_2), and the legs (Ao_3). The venæ cavæ (SVC, IVC) carry the blood to right auricle (RA), whence it passes to the right ventricle (RV), the pulmonary artery (PA) and the lungs. The portal vein (PV) divides into capillaries as it passes through the liver (H).

The Mechanism of the Circulation.—The heart is often compared to a great pump which drives the blood through the blood-vessels. This, however, cannot be the whole story, as is apparent enough the moment we begin to think about the matter.

Think, for example, of such a phenomenon as blushing. Blushing is obviously due to a greater amount of blood being driven through the capillaries of the face. Now, although the heart might, by beating more rapidly, drive more blood than usual to the face, it could not conceivably by its own action drive an excess of blood *specially* to the face.

Blushing is only one example of what is constantly going on in all parts of the body. Whenever any part of the body is used, it demands an extra supply of blood, and this is immediately furnished. During active exercise blood flows more freely to the muscles, during digestion to the stomach and intestines, during mental work to the brain. Most of us have experienced the tendency of our feet to become cold when we have been engaged with brain work.

The explanation of this nice regulation of the blood-flow is found in the structure of the arteries. You will remember that there is, in the walls of these vessels, unstriped muscle fibre. This muscle, like the muscles of the body generally, is governed by nerves, and according to the influence of these nerves the muscle fibre is contracted or relaxed. The muscle fibre is most abundant in the walls of the smaller arteries round which it is wrapped. When the muscle fibre is contracted, the calibre of the artery is diminished, and when the muscle relaxes the calibre is increased. In such circumstances we speak of the artery as being constricted or dilated. When an artery is constricted less blood can flow through it, and thus less blood goes to the organ it supplies. When an artery is dilated blood flows through it more easily, and thus the territory it supplies receives more blood.

The nerves which go to the blood-vessels are called **vaso-motor** nerves. Like other nerves they are connected with the central nervous system.

The result of this regulation of the blood-flow is, that the circulation is never the same for two minutes together. With the continually varying demands of the organs and tissues of the body, there are constant local changes in the rapidity of the blood-flow.

The structure of the blood-vessels has another important influence on the blood-flow. It has been stated that the blood-vessels are elastic. Now when the heart contracts and drives the blood into the great arteries, these are distended, and the subsequent contraction of their elastic walls aids in driving the blood on its course. The work of the heart is thus rendered more easy than it would be if the arteries were rigid tubes.

The Pulse.—With each beat of the heart, there passes into the arteries from the aorta a wave of distension, and this is the cause of the pulse. The pulse-wave dies out before reaching the capillaries. There is no pulse in either the capillaries or the veins.

It takes an appreciable time for the pulse-wave to travel from the heart to the wrist, as you will have little difficulty in making out for yourself if you will feel your heart beat with your right hand, and at the same time place your left fore-finger over the pulse of your right wrist. The pulse will be felt quite appreciably *after* the heart-beat. The actual time is about one-eighth of a second.

The passage of the pulse-*wave* must not be confounded with the passage of the blood itself. Just as the waves of the sea run in towards the shore more rapidly than the rising tide, so the wave started by each heart-beat travels more rapidly than the blood which is driven into the arteries.

The Influence of Respiration on the Circulation.—The heart is not the sole driving power of the circulation. Every time

we take a breath, the expansion of the chest diminishes the pressure within the heart, and the result of that is that blood is drawn towards the heart from the great veins of the neck and abdomen. Moreover, the diaphragm, or great muscular partition between the chest and abdomen, descends and presses upon the abdominal viscera. Thus pressure within the abdomen is increased, and blood is pressed onward from the abdomen to the heart. Expiration, naturally, has an opposite tendency, as can be well observed during powerful expiratory efforts. When a man is blowing a trumpet, his face often becomes distinctly congested, and in a child suffering from whooping-cough the face becomes blue or purple in colour during the paroxysms, which consist of a rapid succession of strong explosive expirations with no inspiration until the spasm ends in the characteristic crow. In ordinary quiet breathing, however, nothing of this sort occurs. During expiration the flow of blood towards the heart is slightly slowed, but on the whole, and taking inspiration and expiration together, we may say that respiration materially aids the work of the heart.

Respiration also assists the circulation through the lungs. During inspiration the lungs expand and hold more blood. During expiration the lungs contract, and their contraction helps in driving the blood on through the pulmonary veins to the heart.

The Effect of Movement.—During exercise muscles require a large supply of blood. The contractions of the muscles squeeze the veins, and force the blood to flow more rapidly towards the heart. The heart, thus receiving a greater volume of blood, beats more rapidly. In this way the circulation is quickened throughout the body. Moreover, during active exercise, the respirations become not only more frequent but more powerful, and consequently the influence of the respiratory movements on the circulation is increased. The constant change of posture involved in exercise also

helps the circulation. If one posture is maintained for too long a time discomfort is experienced. In dependent parts of the body the veins become distended and the blood tends to stagnate. In maintaining an active circulation, therefore, not only in the muscles, but throughout the body, exercise is of great importance. We cannot expect to remain healthy unless we take a sufficient amount of exercise.

The Circulation in Childhood.—The chief peculiarity of the circulation in childhood is the comparative rapidity of the heart's action. Thus the pulse-rate in infancy is normally over 100; between two and six years it is from 90 to 105; from seven to ten years it is from 80 to 90. These are the rates during absolute quiet. The least exertion or excitement increases the rapidity still further.

The heart is relatively slightly larger than in the adult and the blood-vessels are more elastic. Consequently the heart can easily cope with the increased work which the active habits of children involve. Increased strain is thrown upon the heart by severe exertion, as in lifting heavy weights; by sudden exertion, as in the tackling in football; and by prolonged exertion, as in long distance running. All these varieties of strain are necessarily involved in school athletics, yet it is very rarely that active energetic games do boys anything but good. But it should be remembered that very real danger of over-strain does exist for boys who are suffering from any weakness of the heart, who are in bad form, especially after an illness, or who have actual heart disease. These conditions can be discovered only by medical examination.

CHAPTER XII

THE FLUIDS OF THE BODY

THE BLOOD

Blood is a red fluid which forms about one-twentieth of the total weight of the body. When withdrawn from the body it becomes solid or clots.

Clotting or Coagulation.—Tie a cord firmly round the base of a finger so that the finger becomes congested. With a sharp needle prick the skin near the root of the nail. The skin is very thin here, and may be pricked with scarcely any pain. Allow a large drop of blood to escape. Catch it on a plate and cover it with a watch-glass. Observe the dark red colour of the blood. Squeeze out another drop of blood, spread it thinly on a plate, and expose it to the air. Notice how it becomes of a brighter red in the course of a minute or two. This is due to the absorption of oxygen from the air.

In a short time the drop of blood under the watch-glass will become quite solid. One can study clotting better by obtaining several ounces of blood in a glass beaker or tumbler. The clotting starts from the glass and spreads into the blood which, in a few minutes, sets into a jelly. In the course of a few hours this jelly separates into two portions, a solid clot and a clear fluid called *serum*. The clot consists of a network of fine threads of *fibrin*. Fibrin is an insoluble protein substance. It is derived from a soluble substance in the blood called *fibrinogen* under the influence of *thrombin* which is liberated from damaged tissue cells or white blood corpuscles. Thus an injury which causes bleeding liberates the material necessary to arrest the hæmorrhage. This process of clotting closely resembles the curdling of milk (*see* p. 18).

The clotting of the blood is a very useful character because it is by this means that bleeding is arrested. There are people, popularly called "bleeders," whose blood does not possess this character. In such cases what would, to most of us, be a very trivial injury, may give rise to very serious consequences. A blow on the nose or the extraction of a tooth may cause fatal hæmorrhage.

Microscopic Appearances.—Under the microscope, blood is found to consist of solid particles, called *corpuscles*, floating in a clear fluid, the *plasma*. Plasma differs from serum in that it contains fibrinogen. The corpuscles are of two kinds, red and white.

The Red Corpuscles.—The red corpuscles are circular discs slightly hollow in the centre. They are bright red when seen in the mass, but under the microscope they appear yellowish. They have a tendency to stick together, and when the drop which is being examined has stood for a few minutes, the red corpuscles are often found in little groups like rolls of coins. Such rolls are called *rouleaux*. The corpuscles are of uniform size, and 3200 of them laid flat in a row would measure one inch. A small drop of blood (one cubic millimetre) contains 5,000,000 red corpuscles.

The red colour is due to a pigment called hæmoglobin, which forms the bulk of the corpuscle. This substance is of a protein nature and contains iron. It has a strong attraction for oxygen, which it absorbs, becoming of a brighter colour. It was this process which made the blood on the plate change to a brighter red. When the blood circulates through the lungs it is the hæmoglobin that absorbs the oxygen from the air we breathe. It does not hold the oxygen very tightly, but parts with it to the tissues through which the blood flows.

The White Corpuscles.—The white corpuscles or leucocytes are much less numerous than the red. A cubic millimetre

contains about 6000, but the number varies considerably. It is greater after a meal, and in feverish illnesses it may be very much increased. The white corpuscles are slightly larger than the red. There are several varieties of them, but all are evidently complete cells in which one can recognise a nucleus in the protoplasm. In some the protoplasm is clear; in others it is granular. In some the nucleus is comparatively large, almost filling the cell; in others it is smaller. The most abundant of the white corpuscles is a cell with granular protoplasm and a nucleus which is almost divided into several pieces. This form, in particular, reminds one of amœba, and indeed it may be seen moving about just like an amœba if the blood which is being examined is kept warm. It is known that these corpuscles often creep through the walls of the blood-vessels and wander about in the tissues outside. It has even been discovered that when disease germs get into the body, these corpuscles, escaping from the blood-vessels in enormous numbers, attack them and eat them up. When engaged in this observation they are known as phagocytes or devouring cells. Many, however, die in the attack; and the matter which is found in an abscess contains the dead bodies of the combatants—germs and white cells united in death. Those who have suffered from an abscess, a whitlow,

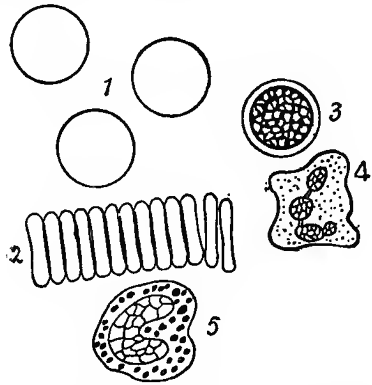

FIG. 45. Blood corpuscles, highly magnified. 1. Red corpuscles. 2. Red corpuscles seen edgewise. 3, 4, 5. Varieties of white corpuscles—viz. lymphocyte, polymorpho-nuclear, and eosinophile.

or a boil may best appreciate the fact that the pain they suffered was due to the progress of a battle in which the forces of the body were ranged against an enemy which had succeeded in penetrating within the gates.

Origin of the Corpuscles.—The corpuscles are continually being worn out and as continually renewed. The birth-place of the red corpuscles is the marrow in the bones. In the marrow are cells with a dense nucleus and clear protoplasm, which undergo active multiplication by dividing. Each cell divides into two. Each of these into two more, and so on. Ultimately cells are formed which contain hæmoglobin, and which look just like red corpuscles, except that a nucleus is present. By-and-by the nucleus disappears. Probably it is extruded. Anyhow, the cell, rid of its nucleus, collapses into a flat disc, which we recognise as a red corpuscle. In all mammals the red corpuscles in the circulating blood have no nuclei, but in all other vertebrate animals—birds, reptiles, amphibians, fishes—the red corpuscles retain their nuclei. Moreover, in these animals the red corpuscles are oval instead of round. One can therefore easily determine whether a blood-stain is due to mammalian blood or not.

The white corpuscles are formed, some in the bone marrow, and some in the lymphatic tissue, which is described below.

Other Constituents of Blood.—The plasma of blood contains *proteins*, which are used in the construction of tissue and the repair of waste. *Fat*, derived from the food, and *sugar*, of the kind called glucose, are present in blood and are used up in the tissues—the sugar in the muscles especially.

The blood also contains waste substances, such as *urea*, which is excreted by the kidneys. and salts such as sodium chloride (common salt), sodium carbonate, sodium phosphate, and salts of potash, lime, and magnesium.

Bloodlessness.—Bloodlessness is a very common affection, especially in young women. In such cases there is no diminution in the quantity of blood, but the red corpuscles are

less numerous than normal, and there is a still more serious deficiency of hæmoglobin. The blood is therefore more watery than it should be, and in some cases this may be quite evident even to the naked eye in a drop from a pricked finger. The sufferer becomes pale, and as there is not sufficient hæmoglobin to carry oxygen through the body, breathlessness and languor are complained of. The causes of the condition are not fully known. Constipation, insufficient or unsuitable food, want of out-door exercise, the change from a country to a town life, have all been blamed, and doubtless any of these may act as contributory causes.

FIG. 46. Lymphatic gland, showing lymphatics entering and leaving it.

LYMPH

The blood is strictly confined to the blood-vessels. The lymph is a fluid which is partly contained in minute vessels with very thin walls, called lymphatics, and partly free in the tissues of the body. It is a clear, slightly yellow fluid, which is largely derived from the blood, having soaked through the walls of the blood-vessels. It circulates slowly but constantly through all the tissues of the body—from the blood into the tissues, and from the tissues back into the blood again.

From all parts of the body the lymph drains into lymphatic vessels. These, in their course, press through little round or oval structures called **lymphatic glands.** These glands vary in size from a pea to a hazel-nut. They are composed of a meshwork of fibrous tissue, with very numerous cells like white blood corpuscles in their meshes. These cells are constantly multiplying, and some of them are carried off by the lymph as

it flows through the glands. Ultimately the lymphatic vessels open into veins, and thus the lymph, with the cells it has washed out of the lymph glands, is poured into the blood. A tissue very similar in structure to the lymph glands is found in the tonsils, in the walls of the intestine, and in other places.

The lymph glands occur in groups in such places as the armpit, the groin, behind the knee, below the jaw. There are a great many of them in the abdomen, and a large group at the root of the lung.

Besides serving as a source of white blood corpuscles, the lymph glands have another function. They filter the lymph and remove from it poisons which might otherwise get into the blood. This is obviously a very important duty, but it is also a risky one for the lymphatic glands themselves, which often become swollen and inflamed. This may lead to the formation of an abscess, or the inflammation may settle down, leaving the glands permanently enlarged. Such enlarged glands are very common in children, especially if they are weakly or badly nourished. The source of irritation is commonly sore throat, decayed teeth, skin eruptions, or neglected sores. A serious aspect of such enlarged glands is that they may become the seat of tubercular disease.

Hæmo-lymph glands are found chiefly in the abdomen. They can usually be seen like large drops of blood in the carcase of a sheep hanging in a butcher's shop. They resemble ordinary lymphatic glands in their general structure, but they contain large spaces in which red blood corpuscles—presumably effete corpuscles—are broken down and destroyed.

CHAPTER XIII

RESPIRATION

We have already seen that the food we eat undergoes within the body a chemical change which is akin to the combustion of coal or wood. Now combustion implies oxidation. Without oxygen fire will not burn. During combustion the oxygen of the air unites with the carbon in the fuel, and carbonic acid is produced.

So within the body, as within the steam-engine, combustion is continually going on. The oxygen necessary for this combustion is derived from the air. The oxygen of the air is absorbed into the blood, and carbonic acid gas is given off in its stead. This process is called respiration, and it takes place in the lungs.

The Air we breathe.—Atmospheric air contains about 21 per cent. of oxygen, 79 per cent. of nitrogen, and a trace of carbonic acid. It contains also a very variable proportion of water vapour. When air is breathed it is warmed almost to the temperature of the body, and a large amount of moisture is added to it, as we readily recognise by the condensation of the water vapour in our breath in cold weather. Carbonic acid is added to the extent of 4.3 per cent., and the oxygen lost amounts to 4.7. The proportion of nitrogen is not altered. These changes are indicated in the following table:

	Atmospheric Air		Respired Air.
Oxygen . .	20.9	—	16.2
Nitrogen . .	79	—	79
Carbonic acid .	0.04	—	4.34
			+ water vapour.
			+ heat.

The Changes in the Blood.—The blood carried to the lungs by the pulmonary arteries is impure or venous, and is of a dark red colour. It contains waste products, including carbonic acid, derived from the tissues of the body.

In the lungs the carbonic acid is given off into the air, and oxygen is absorbed. The oxygen is taken up by the colouring-matter of the blood called hæmoglobin. When oxygen unites with hæmoglobin the latter becomes bright scarlet, and this is the colour of pure or arterial blood. The pure blood from the lungs is carried back to the heart by the pulmonary veins, and is distributed by the arteries throughout the body. In the different tissues through which the blood passes there are substances which are greedy for oxygen, and these gradually abstract the absorbed oxygen, with the result that very little of it is left when the blood reaches the lungs again.

The Organs of Respiration.—On its way to the lungs the air passes through the nose, the pharynx, the larynx, the trachea, and the bronchi. These constitute the respiratory passages.

The **nasal cavities** are two in number, one corresponding to each nostril. They are separated from one another by a partition called the septum of the nose. The floor of the cavities is formed by the palate, which separates them from the mouth. The roof is formed by part of the ethmoid bone, through which pass the fine nerves of smell. From the outer wall of each cavity there project inward three very thin plates of bone each loosely rolled up like a scroll. These are called the turbinate bones. The whole interior of the passages is lined by a thick moist mucous membrane which is plentifully supplied with blood. This mucous membrane is spread over both sides of the turbinate bones. There is thus a very large surface of mucous membrane altogether, and therefore the air which is breathed through the nose is heated by the warm blood circulating in the membrane before it passes to the lungs. Any small dust particles in the air are likely to stick to the moist surfaces and thus the air is filtered. The hairs situated

within the nostril help to filter the air by obstructing the passage of grosser dust particles.

The two nasal passages meet together behind, and open into the pharynx, which forms the back of both nose and throat.

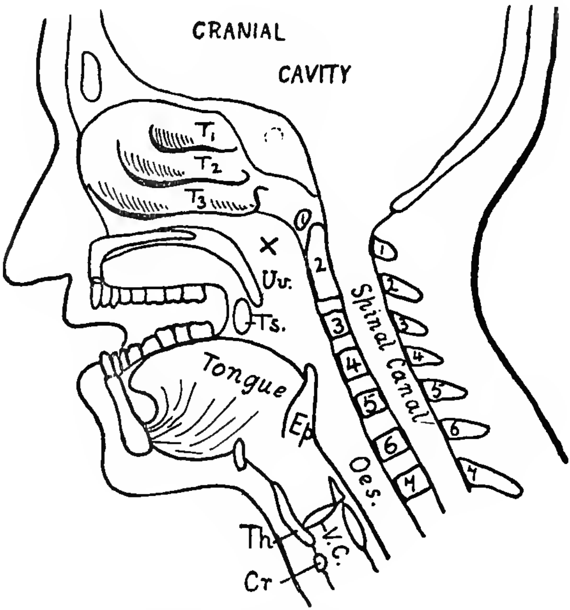

FIG. 47. The head divided vertically to show interior of nose. T_1, T_2, T_3. The turbinate bones. Uv. Uvula. Ts. Tonsil. Ep. Epiglottis. Th. Thyroid, and Cr., cricoid, cartilages. V.C. Vocal cords. Oes. Œsophagus. 1, 2, 3, &c. The bodies (in front) and the spinous processes (behind) of the vertebræ of the neck. The X shows the place where adenoids grow.

This region, often called the naso-pharynx, is the site of the little growths called adenoids, which are so common in children. Into it, just above the soft palate, there opens a tube which acts as a ventilating shaft for the ear. This is called the Eustachian tube. It is an important structure, and if it is blocked up, as it sometimes is, deafness results.

The pharynx has muscular walls which play an important part in swallowing. At its lower end the pharynx opens into the œsophagus below and the larynx in front.

The larynx is the organ in which the voice is produced. It is situated in the front of the neck, where its firm cartilages can easily be felt.

Below the larynx is the trachea or windpipe.

Procure from a butcher the lungs of a sheep. With the lungs you will obtain the trachea and probably the larynx also. The **trachea** is a tube of considerable size which is kept open by C-shaped hoops of cartilage in its walls. It is lined by mucous membrane. The cells which cover the surface of this mucous membrane are of the kind called ciliated. That is to say, they are provided with exceedingly fine hair-like processes which, during life, are in continual motion. The movements of the cilia occur in such a way as to produce an upward current in the viscid fluid, which moistens the interior of the trachea. The result of this is that particles of dust which have been carried down into the trachea and have adhered to its walls are gradually borne upwards to the pharynx, and so are prevented from entering the lungs.

The lower part of the trachea is situated within the chest. It divides into the two main **bronchi**, one of which passes into each lung. Within the lung the bronchus gives off branches like a tree. By splitting up the bronchus with a pair of scissors you will be able to observe how the branches become smaller and smaller and finally so minute that they cannot be followed further. The structure of the bronchi resembles that of the trachea, but in the smaller bronchi the cartilage is in the form of irregular plates instead of hoops.

The Structure of the Lungs.—The two lungs and the heart occupy almost the whole of the cavity of the thorax. Each lung is a conical organ. The apex extends up into the root of the neck, to a little above the level of the collar bone. The base is concave and rests upon the diaphragm, a muscular

partition which separates the chest from the abdomen. The front edge of each lung overlaps the heart. The part of the lung where the bronchus enters is called the root, and the root of the lung contains the pulmonary arteries and veins as well as the bronchus. Except at its root the lung is not attached to anything, but it is so closely applied to the surrounding structures that slight grooves corresponding to the ribs can be

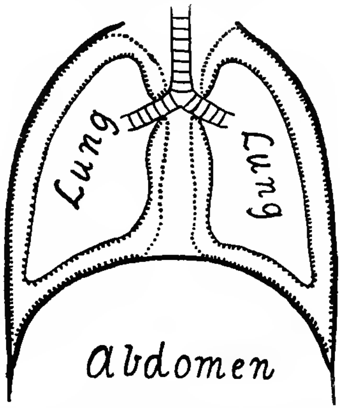

FIG. 48. Diagram showing arrangement of pleura (the dotted line). The pleura covering the lung is really in contact with that lining the chest wall. Between the chest and abdomen is the diaphragm.

seen on a fresh specimen. The surface of the lung appears smooth and shiny owing to the presence of a closely adherent membrane called the **pleura**. The pleura envelops the entire lung to its root, and there it is folded back on itself and a second layer lines the chest wall. Thus when the lung moves, as it does in breathing, the layer of pleura covering the lung rubs against the layer lining the chest wall, and as both layers are exceedingly smooth and lubricated by a little fluid, friction is reduced to a minimum. The pleura thus serves the same purpose as the synovial membrane of a joint. Pleurisy is an inflammation of the pleura. The part inflamed becomes

roughened and exceedingly tender, and so breathing becomes very painful.

The smallest bronchi in the lung end in little sacs, each of which has a number of smaller sacs opening into it. These

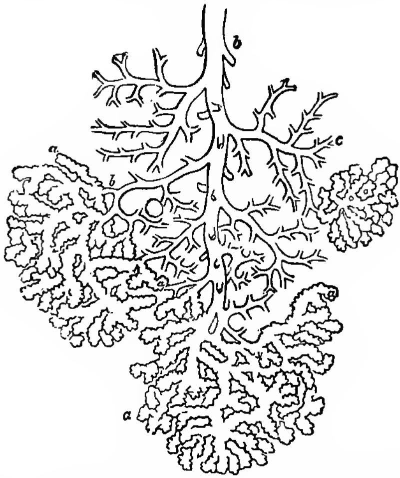

FIG. 49. **Lung.** Diagram showing how an air tube branches and ends in air sacs. *a*. Air sacs. *b*. Bronchial tube. *c*. Little bronchial tubes.

last are called the **air cells.** They are of very small size and their walls are formed of an extremely thin membrane. The pulmonary artery, which enters the lung along with the bronchus, divides and subdivides within the lung and finally ends in a network of fine capillaries between neighbouring air cells. Therefore between the air in the air cells and the blood in the capillaries there intervenes nothing but two fine membranes—the wall of the air cell and the wall of the capillary. This double layer of membrane is so thin that gases can easily diffuse through it.

Now take the lung whose bronchus has not been split up. Push the nozzle of a pair of bellows into the bronchus and blow. Notice how readily the lung can be inflated. Notice

also that as soon as the bellows are removed the lung collapses. This is due to the presence of a great deal of elastic tissue in the substance of the lung.

Cut off a small piece of lung and squeeze it to press the air out. Throw it into water and you will find that it floats. This is because, even after squeezing, the lung retains a considerable amount of air.

The Mechanism of Respiration.—In breathing, what we actually do is this. First of all we expand our chest. This naturally diminishes the pressure within, and air rushes in from outside. Then we allow the chest to return to its original condition and the air is driven out again.

Note these words—"We expand our chest"—"we allow the chest to return." The words may be taken literally, for inspiration is a muscular act; while expiration, in quiet, tranquil breathing, involves almost no muscular contraction at all.

Suppose you take a pair of bellows and lift the upper board. This will reduce the air pressure within the bellows, and outside air will enter. If you now let go the board it will fall into place again and air will be expelled. The bellows were opened by muscular effort and closed by gravity. But if you wish to blow the fire you will exert muscular power not only in opening, but also in closing the bellows, in order to get a strong current of air.

Here also the analogy holds good. In forced breathing, as when we are out of breath, muscular effort is brought into play in both expiration and inspiration.

In *drawing a breath* the size of the chest may be increased in three directions—from before backwards, from side to side, and from above down.

1. Increase from *front to back* is effected by raising the ribs. The ribs slant downwards considerably from the spine so that their attachment to the sternum is lower than their attachment to the vertebræ. The more the ribs slope the nearer the sternum comes to the vertebral column. When we

draw a long breath the ribs become more nearly horizontal, and as they rise they push the sternum forward.

2. Increase of the *transverse* diameter of the chest is also effected by the raising of the ribs. Each rib forms a curve, and the outer part of the curve sags down a little below the level of a line joining the extremities of the bone. When we draw a breath this downward droop diminishes and the size of

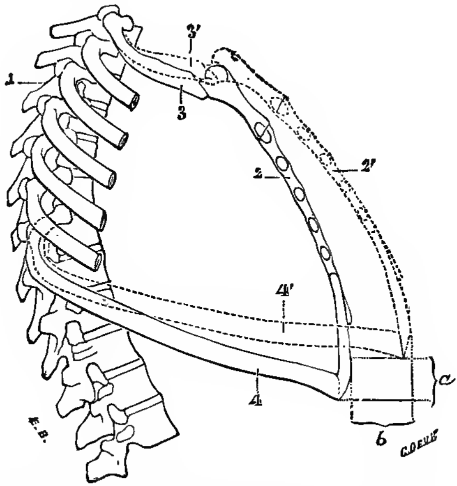

FIG. 50. Diagram to show how, as the ribs move upwards, the sternum goes forwards, and so increases the size of the thorax during inspiration. 1. Spinal column. 2. Sternum. 3. First rib. 4. Seventh rib. 2', 3', 4'. Position in inspiration. *a*, *b* indicate the extent of movement.

the chest from side to side is correspondingly increased. This increase can easily be made out in the lower part of the chest, where it is greatest.

3. In the *vertical* direction the size of the chest is increased by the descent of the muscular diaphragm. The descent of the diaphragm pushes upon the abdominal viscera and causes some protrusion of the abdominal wall.

Types of Breathing.—In children breathing is effected

chiefly by the movements of the diaphragm, as may be recognised from the resulting abdominal movements.

In women, respiratory movement is most apparent in the upper part of the chest

In men the movement is chiefly abdominal, but there is some chest movement also, especially of the lower ribs.

Hence we speak of abdominal, thoracic, and costo-abdominal types of breathing, characteristic respectively of children, women, and men. The difference between the type of breathing in men and women probably results from the difference in clothing.

The Muscles concerned in Respiration.—In quiet breathing the ribs are raised by the **intercostal** muscles. These muscles are situated in the spaces between the ribs, to the contiguous borders of which they are attached. There are two layers of muscles. The fibres of the *external* intercostal muscles slope downwards and forwards, those of the *internal* downwards and backwards. It is generally agreed that the outer muscles, when they contract, raise the ribs, but there has been a great deal of discussion as to whether the internal intercostal muscles also act in this way, or whether their contractions tend to draw the ribs down again. Experiments have been tried by fixing pieces of elastic to the ribs of a skeleton so as to represent the muscles, but it is not possible to imitate exactly the conditions present during life.

The **diaphragm**, which forms a partition between the chest and the abdomen, is partly muscular and partly tendinous. The muscular fibres arise in front from the back of the breast bone and the cartilages of the ribs attached to its lower part; at the sides from the lower ribs; and behind from the lumbar vertebræ by two strong bands of muscle called the pillars of the diaphragm. From all these attachments the muscular fibres arch upwards and inwards and are inserted into a tendinous area called the central tendon of the diaphragm, which lies just beneath the heart. The diaphragm forms a

high arched dome. When the muscular fibres contract the dome is somewhat flattened, the central tendon is drawn down, and the size of the chest is thus increased from above down. As soon as the diaphragm stops contracting the

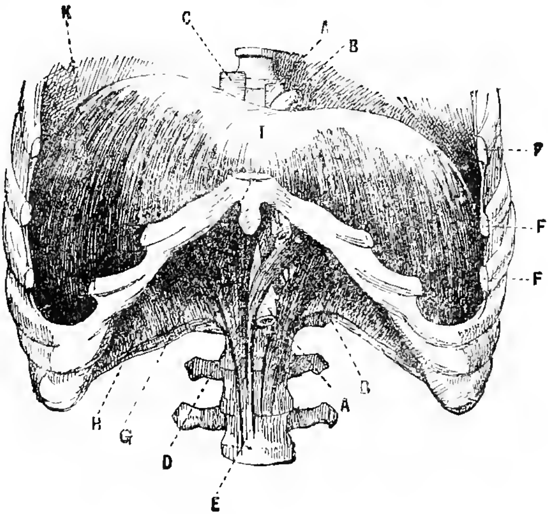

FIG. 51. The dome-shaped diaphragm. A. Aorta. B. Œsophagus. C. Vena cava inferior. D. Muscular pillars of the diaphragm arising from the spinal column E. F. Ribs, and G, sternum, sawn through so as to allow removal of the front of the thorax. H. Hind, and K, front, muscular sheet, and I, central tendinous part of diaphragm.

elastic recoil of the abdominal wall presses it back again to its previous position.

Inspiration is thus brought about by the contraction of the intercostal muscles and the diaphragm. As soon as these muscles cease to contract, the elasticity of the ribs and their cartilages and of the abdominal wall causes the chest to resume its previous form. Moreover, we have seen that the lungs also are elastic, and their elasticity helps to drive the air out as soon as the inspiratory muscles cease to contract.

A Long Breath.—When we draw a long breath voluntarily, and when we breathe deeply during active exercise, several muscles which are not called into play in quiet breathing assist the respiratory movements. These muscles are called the extra-ordinary muscles of respiration. Several of them have been mentioned already in the chapter dealing with the muscles.

During inspiration the expansion of the chest is assisted by some of the powerful muscles attached to the chest wall. Elevation of the shoulders enables some of these muscles, such as the great pectoral muscles, to act to better advantage. It is for this reason that "arm raising," which necessarily involves elevation of the shoulders, is often practised during deep breathing exercises.

One of the most powerful of the extraordinary muscles of respiration is the **serratus magnus** (Fig. 37), which lies between the scapula and the chest wall, to both of which it is attached. Its usual action is to draw the shoulder forward, but if the shoulder is fixed it pulls on the ribs and so expands the chest.

During forced expiration the principal muscles called into play are those of the abdominal wall. When these contract they not only pull the ribs and sternum downwards, but they press the abdominal viscera against the diaphragm, which is thereby pushed up against the lungs.

The Amount of Air respired.—During quiet breathing the amount of respiratory movement is comparatively slight, and the air which passes in and out of the lungs would be found, if collected, to measure some 25 or 30 cubic inches. This air is termed **tidal.** By drawing a long breath one can quite evidently draw into the lungs several times as much air as passes in during quiet breathing. The extra air so inspired is called **complemental.** By a forced expiration one can also breathe out an additional amount of air, and this is called **reserve.** The complemental air and the reserve air each

amount to about 100 cubic inches. The most powerful expiration, however, fails to expel all the air from the lungs. After the reserve air has been driven from the lungs about 100 cubic inches of air still remain. This is called the **residual** air.

The total amount of air which a man can expire after taking a deep breath is a fair indication of the size and muscular development of his chest, and it has been termed the *vital capacity.* According to the figures given above the vital capacity of an average man is 230 cubic inches. One can easily find one's own vital capacity by inverting in a basin of water a large glass vessel, also filled with water, and expiring into it through a tube. The expired air collecting in the vessel will drive out the water, and after as long an expiration as possible has been made, a mark can be placed on the vessel to indicate the level to which the water has been driven. The capacity of the glass vessel to the level of the mark obviously corresponds to the vital capacity of the chest. An instrument specially made for gauging the vital capacity is called a spirometer.

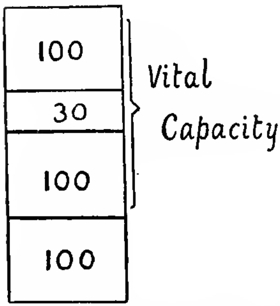

FIG. 52. A. Complemental, B, tidal, C, reserve, D, residual air in cubic inches.

The possession of a large chest does not necessarily imply a large vital capacity. It is not uncommon to find men who have very large chests, but whose vital capacity is low because the movements of the chest are deficient. An average man should be able to expand his chest three inches or more. Deficient power of expansion may be associated with poor chest development, and may therefore be an indication of the need for breathing exercises. But in the cases referred to above the defective chest movements may be due to a loss of

elasticity in the lungs. Such a state of things may arise in players upon wind instruments whose lungs have become over-distended and whose chests have therefore assumed permanently the inspiratory position. While, therefore, breathing exercises are of the greatest value for improving the development of the chest, it is possible to overdo them There is, however, little danger of overdoing them except by expiring against resistance.

A consideration of the amount of air respired in different circumstances will indicate another way in which breathing exercises are of value. In quiet breathing the tidal air drawn into the chest at every breath mixes with 200 cubic inches already in the lungs. Consequently the proportion of pure air in the lungs is never more than 30 : 230. But when we expire the reserve air and then draw in as long a breath as possible the proportion of pure air in the lungs at the end of inspiration will be 230 : 330. By deep breathing therefore we not only draw a much larger *amount* of air into the lungs, but we increase the *proportion* of pure air, roughly speaking, from one-seventh to two-thirds. The blood, therefore, has a much better chance of absorbing oxygen and getting rid of carbonic acid.

Special Respiratory Movements.—*Coughing* consists of an inspiration followed by a powerful expiration, during which the glottis is constricted but is forced open repeatedly by the expiratory blast. The strong expiratory current tends to expel secretion or foreign substances from the respiratory organs.

Sneezing consists in an inspiration followed by a powerful sudden expiration, during which the soft palate is drawn down and air forced through the nose.

Hiccough consists in sudden reflex contractions of the diaphragm causing inspirations which are cut short by spasmodic constriction of the glottis.

Yawning is a deep, involuntary inspiration, associated with

opening of the mouth and often with stretching of the limbs. These movements quicken the circulation and help to improve the supply of blood to the brain.

Rate and Rhythm of Breathing.—The rate of breathing is influenced by several factors. Thus it may be modified by will, and is altered by excitement or emotion. Posture has an influence and exercise quickens the rate. Age, also, is an important factor, as is shown in the following table:

Under 1 year.	Average rate	44	per minute.
„ 5 years.	„	26	„
„ 20 „	„	19	„
Adults	„	16	„

In adult life the rhythm is fairly regular. In early childhood, and especially in infancy, the breathing is often very irregular when the child is awake and active. The sight of something interesting may make the child hold his breath, and this pause may be followed by several quick panting respirations. Inspiration is much more rapid than expiration. Expiration follows inspiration immediately but is itself followed by a slight pause before the succeeding inspiration. This regular succession is sometimes altered, so that the respiratory pause appears at the end of inspiration. After the pause comes a rapid expiration followed immediately by a quick inspiration. One often sees this modification in children suffering from pneumonia, and one may observe the same thing in oneself by running till out of breath. I have little doubt that one reason for this modification is that it obviously allows the fresh air drawn in with inspiration to remain in the lungs for a longer time—that is, for a longer proportion of each breath. Like the quickened breathing it is an answer to the increased demand of the body for oxygen.

The Nervous Control of Respiration.—The muscles which cause the respiratory movements do not act of themselves. They are under the control of a special part of the brain.

This is called the *respiratory centre*, and it is situated in the medulla oblongata.

The respiratory centre is very sensitive to the amount of carbonic acid in the blood. Whenever the proportion of carbonic acid in the blood increases, as it does during exercise, the respiratory centre becomes excited and causes the movements of respiration to take place more rapidly. When the carbonic acid is reduced to the normal proportion the rate of breathing falls again.

Asphyxia.—If a man is choked by something blocking up his windpipe or pressing upon it so that air cannot enter, he makes violent efforts to breathe, and as the blood becomes venous, he gets blacker and blacker in the face. The struggle for air grows more and more severe until the whole body is thrown into convulsions. If the obstruction persists, the convulsions suddenly cease, and the man lies unconscious. By this time his heart is beating very feebly, and in a short time it stops, and the man is dead.

Ventilation.—The symptoms just described are due chiefly to the accumulation of the poisonous carbonic acid in the blood. In an inhabited room which is insufficiently ventilated, carbonic acid naturally accumulates and the air therefore becomes unwholesome. The stuffiness of a close room is due, not to the carbonic acid, but chiefly to exhalations from the skin and clothes. The condition is aggravated by the heat of the room. Gas vitiates the air by adding large quantities of carbonic acid, as well as a little sulphur dioxide and other substances. A moderate-sized gas burner will add as much carbonic acid to the air as five people.

For the sake of health it is very important that the air of inhabited rooms should be kept sweet and pure. It is generally taught that a room cannot be considered efficiently ventilated unless the proportion of CO_2 can be kept below .06 per cent. To maintain this standard of purity the air of a room containing 3000 cubic feet would require to be changed

completely every hour if inhabited by one person, and correspondingly more frequently if more persons were present.

Bedrooms should be specially well ventilated because they are inhabited for so many hours at a stretch ; and the modern habit of keeping the bedroom windows wide open all night is to be strongly commended.

VOICE AND ARTICULATION

Voice is produced by the vibration of the vocal cords within the larynx. Articulation is effected by the modification of the voice by the lips, tongue, and palate. The organs named are the instruments of speech. Speech itself is a function of the brain.

The Larynx.—The larynx is situated in front of the neck. It is a funnel-shaped structure, with the narrow end below, where it becomes continuous with the trachea. It is formed of stout cartilages which are connected by thin membrane, and moved by muscles which stretch from one to the other. It is lined by thick mucous membrane.

The **Thyroid Cartilage** is the largest cartilage in the larynx. It is formed of two wings which meet at an angle in front, and produce the swelling in the neck called Adam's apple.

The **Cricoid Cartilage** is shaped like a signet ring (*κρίκος*, a ring). It is situated below the thyroid cartilage. The seal portion of the ring is to the back. The thyroid cartilage is jointed to this part of the cricoid.

The **Arytenoid Cartilages** are two small cartilages shaped like three-sided pyramids. They are perched upon the cricoid cartilage at the back of the larynx.

The **Vocal Cords** are two tough folds of mucous membrane of a white colour which stretch from the angle of the thyroid cartilage in front to the arytenoid cartilages behind.

The **Glottis** is the chink between the vocal cords. Its size varies according to the position of the vocal cords. The vocal cords are always close together in front. Behind, each

cord is attached to a prominent angle at the base of the arytenoid of its own side. The arytenoid cartilages are movable. If they are drawn close and rotated so as to bring their projecting angles together, the glottis is thereby closed.

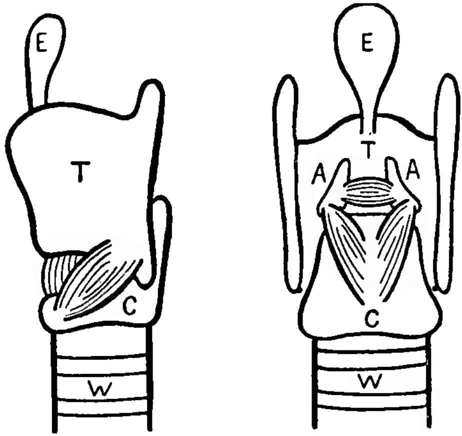

FIG. 53. The larynx. 1. Side view. 2. Back view. E. Epiglottis. T. Thyroid cartilage. C. Cricoid cartilage. W. Wind-pipe. A. Arytenoid cartilages. The crico-thyroid muscle is seen passing from the cricoid to the thyroid cartilage.

If the arytenoids are separated and rotated so as to turn their projecting angles outward, the glottis is thereby thrown widely open.

The **Epiglottis** (Figs. 8, 47, 53) is a thin spoon-shaped cartilage situated at the root of the tongue. Its base is attached to the thyroid cartilage.

The **Hyoid Bone** is situated on the root of the tongue and gives attachment to some of the tongue muscles. It is not

part of the larynx, but is the highest of the hard structures in front of the neck. Below it can be felt the thyroid and then the cricoid cartilage.

Voice is produced by vibrations of the vocal cords. In ordinary quiet breathing the glottis is moderately open. In

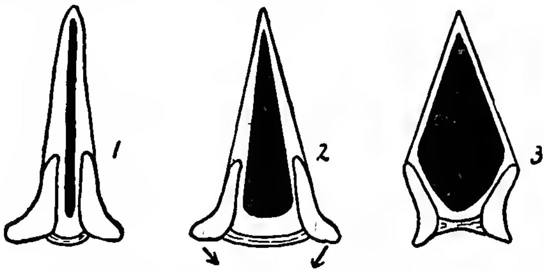

FIG. 54. The glottis. 1. Almost closed. 2. Moderately open. 3. Widely open. The arrows indicate the action of the muscles which rotate the arytenoid cartilages and open the glottis.

speaking a breath is taken. The glottis is then narrowed, and the air is driven out with some force between the vocal cords, which are thus set in vibration.

The **Pitch** of the voice depends on (*a*) the length of the cords; (*b*) their tension. The deeper voice of man is due to the greater length of the vocal cords. The breaking of the voice in boys between thirteen and fifteen years of age is due to the rapid growth of the larynx, whereby the vocal cords become nearly double their previous length.

The tension of the vocal cords can be altered by movements of the thyroid and cricoid cartilages. These cartilages are jointed together behind. In front they can be drawn nearer or further apart. The nearer they are drawn together the tighter do the vocal cords become. These movements can easily be made out by feeling the interval between the cartilages in the neck while singing a scale. As the voice ascends the scale, the cartilages are drawn nearer, and the gap between them is diminished.

The **Quality** ot the voice depends very largely on the cavities of the mouth, nose, and throat, which act as resonating or resounding chambers like the box of a fiddle. The tone of voice can be altered by increasing or diminishing the size of these chambers or the freedom of access to them.

Articulation.—The different vowel sounds are produced by alterations in the shape of the mouth as the breath escapes.

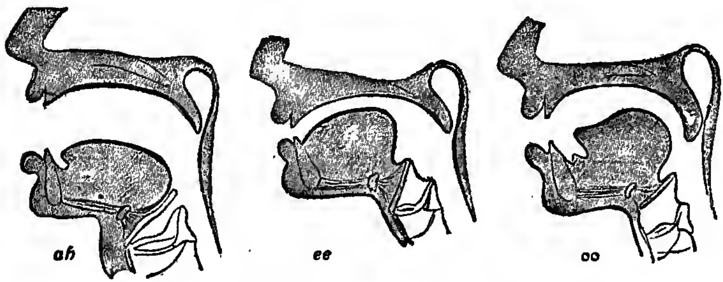

FIG. 55. The shape of the mouth in sounding different vowels.

By gradually changing the shape of the mouth, one may produce such a series of vowel sounds as this—ah, ee, ay, oh, oo. Our English alphabet is not based on physiological principles, for several of the vowels are really diphthongs. Thus *i* is really *ah-ee*, as may be observed by pronouncing the word "nigh" very slowly.

Consonants are produced by partial or complete interruptions of the outgoing blast. The interruption may take place (1) at the lips—first stop position, *e.g.*, P; (2) at the front of the mouth—second stop position, *e.g.*, T; or (3) at the back of the mouth—third stop position—*e.g.*, K. At each of these positions sounds may be produced (1) by closing the passage and bursting it suddenly open, *e.g.*, P; (2) by forcing the air through a narrow passage, *e.g.*, S; or (3) by narrowing and setting the edges in vibration, *e.g.*, R. Nasal sounds are produced by forcing the air through the nose, while the mouth is closed, *e.g.*, M. Some consonants are produced without

an accompanying vibration of the vocal cords. That is to say, they are voiceless. Thus P and B, T and D, K and hard G differ from one another simply in that the first of each pair is voiceless, the second voiced.

Clear articulation demands a very exact co-ordination between the movements of the lips and tongue, of the vocal cords, and of respiration. Stammering is due to a lack of control over these movements.

The following is a classification of the consonants in accordance with the mode of their production:

	Labials.	Dentals.	Gutturals.
Explosives . .	P, B	T, D	K, G
Aspirates . . .	F, V	S, L, Th	Ch (as in loch)
Vibratory . .	—	R (English)	R (French)
Nasal . . .	M	N	Ng

CHAPTER XIV

THE KIDNEYS—THE SKIN—THE WASTE OF THE BODY

THE KIDNEYS. THE EXCRETION OF URINE

THE **kidneys** are situated in the abdomen, one on each side of the spine. Each kidney is about four inches long and two inches broad. From each kidney there comes a tube called the *ureter*, and the two ureters pass down into the pelvis and open into the *urinary bladder*. The kidneys form the urine continuously. The urine, as it is formed, trickles down into the bladder where it collects. When the bladder is full the urine is discharged by the act of micturition.

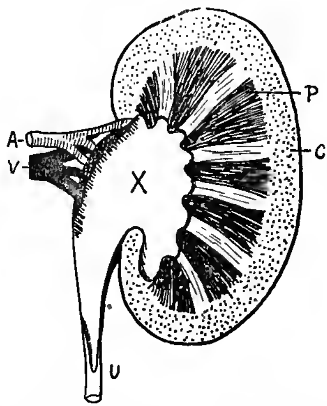

FIG. 56. Diagram of kidney, split open to show the structure. C. Cortex with glomeruli. P. Pyramid with urinary tubules. X. Pelvis. U. Ureter. A. Artery. V. Vein.

Structure of a Kidney.—The ureter, where it is joined to the kidney, is expanded like a funnel. Into this funnel there project several nipple-shaped projections called the pyramids of the kidney. A large artery direct from the aorta carries blood to the kidney, and the blood is returned to the vena cava by a large vein. If a

kidney is split open, one finds that it is a solid organ, and that its substance is arranged in two layers. The layer at the surface is called the *cortex*, and the rest of the organ forms the *medulla*.

When the structure of the kidney is examined under the microscope, it is found that the organ is composed of great

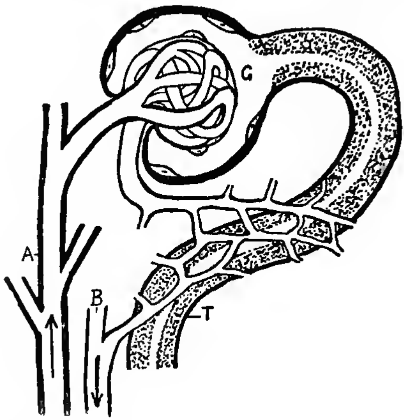

FIG. 57. A glomerulus. A. Artery. B. Vein. G. Glomerulus. T. Urinary tubule.

numbers of very minute coiled tubes. Each tube begins in the cortex in a little round body called a *glomerulus*. It is just possible to see the glomeruli with the naked eye as little red dots. The microscope shows that each glomerulus is formed of the dilated extremity of a tube into which a tuft of capillaries has been pushed, carrying the thin wall of the tube before it. This part of the tube is lined by very thin flat cells. The rest of the tube is lined by much larger cells similar to those found in glands. After leaving the glomerulus the tube is greatly coiled, but it finally opens into a straight tube which runs down into the pyramid and opens at its tip into the dilated upper end of the ureter. A number of the coiled tubes open into the same straight tube.

The Function of the Kidney is to secrete urine. The glomeruli are practically little filters, and as the blood circulates through the tufts of capillaries water soaks from the blood through the thin covering into the beginning of the coiled tubes. There is a rich network of capillaries around the tubules themselves, and from the blood circulating here the cells lining the tubes extract salts and other waste matter. The water from the glomeruli passes down the tubes and dissolves the waste matter separated by the cells, and in this way the urine is formed.

The Composition of Urine.—Urine is an amber-coloured fluid which is denser than water because it holds a good deal of solid matter in solution. The principal solid present is **urea.** Urea is formed not by the kidney, but, as has been mentioned already, by the liver. The kidney simply separates it from the blood. Urea is a waste substance which contains nitrogen, and nearly all the nitrogen excreted leaves the body in this form. The amount of urea secreted by the kidney in twenty-four hours is about an ounce and a quarter. The exact amount is greatly influenced by the nature of the diet. It is greatest if much meat or other protein-containing food is eaten, least during starvation. On a vegetable diet the amount is less than on an ordinary mixed diet.

Besides urea the urine for each day contains about an ounce of salts. The most abundant salt in urine is sodium chloride or common salt. There are also phosphates and urates. Urates are formed by a combination of uric acid with sodium, potassium, and ammonia. Uric acid contains a little nitrogen. The urates are more soluble in warm water than in cold. Hence they are often thrown down as a deposit like brick-dust when the urine cools.

The amount of water excreted by the kidneys is about fifty ounces per day. In hot weather much water escapes from the body in the perspiration, and less is passed by the kidneys. In cold weather the amount of urine is increased

These differences do not affect materially the total amount of solid matter excreted in the urine. When very little urine is being passed, it is concentrated and high-coloured. When the quantity is greater, it appears pale and watery.

In disease various substances may appear in the urine which are not present in health. The chief of these are albumin, sugar, blood, bile, and pus.

The act of passing water, or micturition, is in infancy involuntary, and occurs reflexly when the bladder is full. Gradually a measure of voluntary control is acquired, but throughout early childhood involuntary micturition is readily excited, for instance, during sleep or by fear. Children in whom control is abnormally weak should be trained in regular habits. They should be taught to be ashamed of their weakness, and encouraged to believe that they can prevent "accidents" if they try. But punishment, as a rule, does harm, by increasing nervousness.

(The tests for urine are given in the Appendix.)

THE SKIN

The skin is composed of two layers, the *epidermis* on the surface, and the *dermis* underneath. Between the skin and the deeper structures is a loose layer called the subcutaneous tissue. This allows the skin to slide about to some extent. It contains more or less fat, which gives roundness to the body and serves as a protective cushion.

The **epidermis** is composed of cells closely packed together. The cells on the surface are dry and scaly and form the horny layer of the epidermis, which is specially thick on the palms and soles. The deeper cells are soft, and are continually growing and multiplying. The new cells so formed are gradually pushed upwards towards the horny layer, and as they approach the surface they shrivel up and become dry and scaly in their turn. The cells at the very surface of the skin are constantly being shed or rubbed off by friction, and it is necessary that their places should be taken by others.

The **dermis,** sometimes called the true skin, is a dense

meshwork of connective tissue containing both white and yellow elastic fibres. It is very vascular; that is to say, it is richly supplied with blood. None of the blood-vessels enter the epidermis, but nourishment soaks through to the actively growing cells of the deeper layer. The chief reason why the

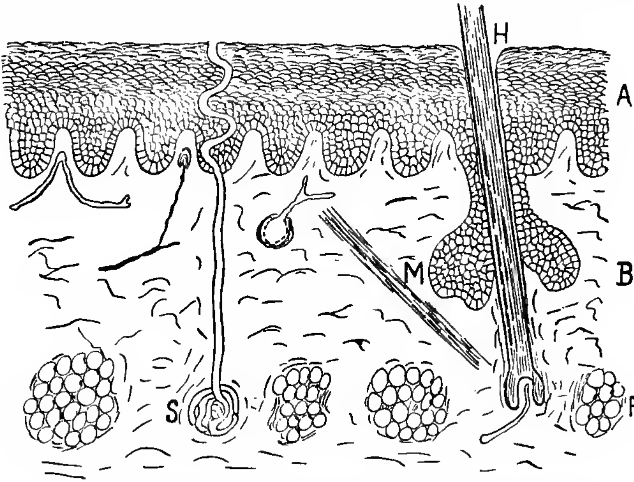

Fig. 58. Section through skin. A. Epidermis. B. Dermis. A nerve fibre can be seen ending in a papilla beside the sweat duct. S. Sweat gland and duct. H. Hair. M is placed between a band of muscle fibre and a sebaceous gland. F. Fat.

surface cells of the epidermis are dry and shrivelled is because nourishment fails to reach them.

The outer surface of the dermis is raised up into numerous little conical processes, which project into the epidermis. These are called the *papillæ* of the skin, and each contains a little meshwork of blood capillaries. Some of the papillæ contain a minute oval body to which a nerve fibre can be traced. These structures are called touch corpuscles. Some nerve fibres penetrate a short distance into the epidermis.

Sweat Glands.—The surface of the epidermis is raised into ridges which are specially well marked at the tips of the

fingers, where they are arranged in arches and whorls and loops. These form a pattern, which is never the same in two individuals. Hence "finger-prints" may be used for purposes of identification. Along each ridge there can be seen with a good lens a row of tiny apertures. These are the mouths of the sweat glands. Each aperture leads into a corkscrew-like duct, which passes right through the epidermis into the deeper part of the dermis, where it coils up into a little *ball*, which is the sweat gland. These glands are specially numerous on the palms and soles. It has been calculated that the entire skin contains over two millions of them. Their total length, therefore, allowing a quarter of an inch for each gland with its duct, must be about eight miles.

Sweat consists almost entirely of water, but a little salt is dissolved in it, and also a trace of carbonic acid. It is always being secreted. Most of it evaporates without forming visible drops of water. This is called *insensible perspiration*. In hot weather and during active exercise sweat is secreted more rapidly than it evaporates, and the skin becomes wet with *sensible perspiration*. The total amount of perspiration lost per day is more than a pint.

The activity of the sweat glands is influenced by the nervous system. Thus shame or nervousness may cause the skin to perspire. As a rule the perspiring skin is flushed with blood, but that increased blood-flow is not the sole cause of increased activity of the glands is shown by the occasional occurrence of "cold sweats," during which very little blood is passing to the skin.

The chief use of the perspiration is to lower the temperature of the body. When water passes into vapour, much heat is absorbed, and the surface from which evaporation takes place is cooled. A great deal of heat is lost from the body in this way. The greater amount of perspiration in hot weather or during exercise is a special adaptation to prevent the temperature of the body from rising above the normal.

Hairs are epidermal structures, being formed of horny matter arising from the epidermis. Each hair grows from a pit in the epidermis called a hair follicle. Into the bottom of the hair follicle there projects a vascular papilla of the dermis which nourishes the root of the hair. Little glands, smaller than sweat glands, open into the follicle. These are called sebaceous glands. They produce an oily secretion which lubricates the hair and makes it glossy. If the secretion is too scanty the hair becomes harsh and dry. If it is too abundant it gives rise to scales of dandruff. In the dermis there are small muscle fibres connected with the roots of the hairs. Contraction of these fibres causes the hair to stand on end. Their action is well displayed when a kitten is frightened.

The **Nails** also are epidermal structures. The surface cells of the horny layer do not fall off but become closely welded together. The nail grows from the nail-bed, formed by the underlying dermis, which is very vascular and supplies nourishment to the deeper growing cells. These therefore multiply rapidly and the nail grows in thickness from beneath, and in length from behind.

The Waste of the Body.—Perhaps it may be useful to summarise the chief facts concerning the loss which is constantly going on from the body.

Water leaves the body in the urine (about 50 ozs.), in the perspiration (over 20 ozs.), and in the breath (about 10 ozs.).

Nitrogen is excreted chiefly as urea, of which the urine contains about $1\frac{1}{4}$ ozs. daily.

Carbon escapes from the lungs as carbonic acid gas. In the course of twenty-four hours the expired air contains about 8 ozs. of carbon.

Salts of different kinds are present in the urine to the extent of about an ounce daily. A much smaller quantity is present in the perspiration.

If we add to these the indigestible parts of the food rejected by the alimentary canal, we find that the total loss from the body of a man is about 8 lbs. daily.

HEAT PRODUCTION AND REGULATION

Heat Production.—Part of the energy derived from food is converted into mechanical work, and part into heat. Wherever chemical changes are going on in the body, heat is produced. Glands during activity liberate a certain amount of heat, especially the liver, which is by far the largest gland in the body. The chief seat of heat production, however, is in the muscles, partly on account of their great total bulk, and partly on account of their great activity.

The Normal Temperature.—The average temperature of the human body in health is about 98.4° F. The internal temperature is slightly higher than that of the skin. Our feelings of heat and cold are no true indication of the actual temperature of the body. At the beginning of a feverish illness, for example, when the temperature of the body is considerably raised, we feel cold and shivery, probably owing to the suddenly increased loss of heat from the skin. Under ordinary circumstances the temperature of the body undergoes very slight variations. A man may feel very warm after active exercise, or cold after sitting still, yet the thermometer will show that the temperature of the body is practically identical on the two occasions.

The Loss of Heat.—Loss of heat takes place through the skin owing to the comparative coldness of the surrounding air. The evaporation of sweat also cools the skin. Heat is likewise lost from the lungs, and a small amount is lost in the urine and fæces.

Regulation of Temperature.—Since heat is always being formed in the body, the temperature would rise steadily if it were not for the constant loss. In all warm-blooded animals

this loss is very nicely adjusted to balance the heat produced. During muscular exercise much more heat is produced, but at the same time the quickened circulation brings more blood to the skin, while the sweat glands secrete more freely and consequently heat is lost more rapidly. Again, when the body is exposed to cold air the blood-vessels in the skin become contracted and the loss of heat is diminished. Shivering is due to contractions of the muscles, and results in the liberation of a certain amount of heat. An Arctic explorer described his men as having been in the habit of "shivering themselves warm."

Heat and Work.—In an engine, as in the body, the fuel consumed gives rise to an equivalent of heat and work. The problem of the engineer is to construct the engine so as to obtain as large a proportion of work as possible. An engine is considered economical if one-tenth of the energy obtained from the fuel can be utilised as motor power. How does the body compare with an engine in this respect? It is possible to find this out by experiment. A man is supplied with a definite amount of food, and the amount of heat an equal quantity of food will give off if oxidised to the same extent as that consumed is ascertained. The man engages in some mechanical work whose amount can be measured accurately. By subtracting the work done from the total energy obtained from the food, the loss of heat may be determined. Many experiments of this kind have been carried out with special precautions against error, which it is unnecessary to describe here. The general result has been to show that about one-third of the total energy liberated may, in favourable circumstances, be utilised as mechanical work, while two-thirds are liberated as heat. The body must therefore be regarded as an extremely economical machine. Moreover the heat produced keeps the body warm, maintaining the temperature which is necessary for the healthy activity of its various organs.

CHAPTER XV

FATIGUE

FATIGUE may be either bodily or mental.

Bodily or Muscular Fatigue.—Muscular fatigue may be studied in a muscle removed from the body. For this purpose a frog is killed and a muscle with a portion of its nerve removed from the body. Such a muscle retains its irritability for several hours. The muscle is suspended by one end, and to the other are attached a small weight and a light lever (Fig. 59). The point of the lever rests against a slowly revolving smoked cylinder. Successive electric shocks are now applied to the nerve and at each shock the muscle contracts and lifts the weight. The lever is also raised and marks on the cylinder a stroke which is longer or shorter according to the vigour of the contraction. It is found that with successive shocks of equal strength the contractions of the muscle grow less and less until at length it ceases to respond to the electric stimulus. The fatigue tracing shows a very regular diminution in the successive contractions.

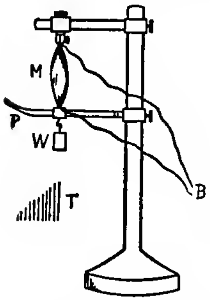

Fig. 59. Myograph. M. Muscle. W. Weight. P. Writing Point. B. Wires from electric battery. T. Tracing made by successive contractions of the muscles.

How can fatigue of this kind be explained? Two theories seem possible. The muscle may use up something which is necessary for contraction, or it may produce something that

interferes with its own action. We may call these the *theory of exhaustion* and the *theory of poisoning.*

Professor Mosso describes an experiment which supports the second theory. If poisons are produced it should be possible to remove them by washing the muscle thoroughly. This cannot be done with pure water, because water injures living muscular fibre, but if a little salt, corresponding to the proportion in blood plasma, is dissolved in the water, a harmless solution is produced. The muscle, then, is thoroughly washed by injecting a weak solution of salt through its blood-vessels. When this has been done the fatigued muscle is found once more to respond readily to stimulation.

A familiar experience supports this view of the causation of fatigue. If, in the course of a walk, one sits down to rest for a few minutes the muscles of the legs become stiff. On resuming the walk this stiffness makes movement difficult or even painful, but in a short time it passes off. One may explain these feelings by the assumption that during rest the poisonous products of exertion accumulate in the muscles. On resuming the walk the circulation is gradually quickened and the blood which now flows freely through the contracting muscles washes the fatigue products away.

The Ergograph.—In order to study fatigue in man Professor Mosso invented the ergograph. This consists of a clamp to which the forearm is fixed so that only the middle finger can move. To the finger is attached by a string a weight which is suspended over a pulley at the end of the table. The finger is made to move either by successive electric shocks or by the will. The person experimented on is asked to lift the weight as high as he can every two seconds (timed by a pendulum or metronome). The successive movements of the weight can be read off on a scale, showing the height lifted, or recorded by a lever on a revolving drum. In this way fatigue tracings can be procured.

Mental Fatigue.—Professor Mosso claims that his instrument

may be used for the study not only of muscular but of mental fatigue. He asks a person to write a fatigue tracing before and after some severe mental work. Less muscular work is done on the second occasion. The difference between the two tracings is taken as the measure of mental fatigue. The ergograph has been largely used in studying fatigue in school

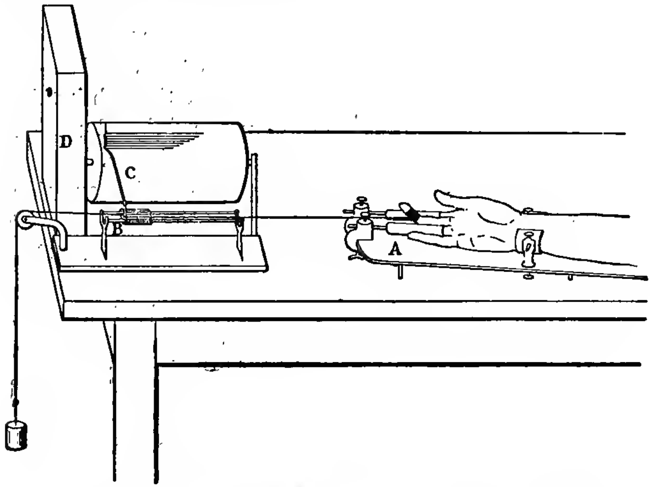

FIG. 60. The ergograph. A. Support for forearm. B. Carrier of style, sliding on two metal rods. C. Style writing on a revolving drum. D. Clockwork for drum.

children with the object of discovering the relative amount of fatigue produced by different lessons, and the most economical method of arranging the school day.

Effect of Fatigue on Nerve Cells.—A few years ago an American, Hodge, made the remarkable discovery that fatigue produces changes in the nerve cells which can actually be seen through the microscope. This observation was made upon bees. The nerve cells of bees captured when issuing from the hive in the morning were compared with those of bees which had finished a hard day's work.

Recovery from Fatigue.—Fatigue tends to increase throughout the day. Experiments with the ergograph show that school-children are more easily fatigued in the afternoon than in the morning, and thus bear out the common-sense view that fatiguing lessons should be taken in the morning, and recreative subjects like drawing and singing in the afternoon. Similar experiments upon adults have been carried out with the object of ascertaining how to obtain the maximum of work with the minimum of fatigue. Such experiments show that it is economical to alternate periods of rest with periods of work. Interruptions are not always a waste of time, but the proper periods for work and rest vary with the individual and the nature of the work. In the case of all persons who work hard a weekly day of rest is physiologically advantageous. Complete recovery from fatigue takes place only during sleep. This is a fact of very great importance in the nursing of the sick. Exhaustion is such an important element in many illnesses, and fatigue occurs so readily both during sickness and convalescence, that everything a nurse can do to promote the quiet restful sleep of her patients must aid their recovery.*

* See *Fatigue*, by A. Mosso (English translation, 3rd edition, 1915. Allen and Unwin).

CHAPTER XVI

THE REPRODUCTIVE SYSTEM

Some of the lower forms of animal life, like the majority of plants, are hermaphrodite. That is to say, the two sexes are combined in one individual. In the human embryo at an early stage a suggestion of this condition is found, for rudiments of both male and female reproductive organs make their appearance. Before long, one set of organs undergoes an arrest of development. The other organs continue to grow and develop and determine the sex of the individual. The organs whose development is arrested do not disappear but persist throughout life in the form of rudimentary and apparently useless structures. The practical importance of this interesting fact is that these structures are markedly liable to disease. They account, for instance, for a considerable proportion of the abdominal tumours to which women are so subject.

THE MALE ORGANS OF GENERATION

The **testicles** are two oval organs, about an inch and a half in length, which are situated in a pouch of skin, connective tissue, and muscle fibre called the scrotum. Before birth the testicles are in the abdomen, but they descend into the scrotum

through a passage called the inguinal canal shortly before the child is born. Each testicle is enveloped in a serous bag or sac, called the *tunica vaginalis*, which is derived from the peritoneum. The testicles produce a secretion called the spermatic fluid which contains the fertilising elements or spermatozoa.

Attached to each testicle is an oval structure called the **epididymis.** This consists mainly of a much coiled tube which, when unravelled—no easy matter—measures about twenty feet in length. It terminates in the *vas deferens* or spermatic duct. The latter passes upwards and traverses the inguinal canal, where in company with blood-vessels and nerves it is bound into a bundle called the *spermatic cord.* Entering the abdomen the spermatic duct immediately turns down into the pelvis and passes along the base of the bladder, eventually opening into the urethra a little in front of the bladder.

The **urethra** is the passage by which the urine escapes from the bladder. It is about 8 inches in length, and is divided into prostatic, membranous, and spongy portions. The prostatic portion is about an inch and a half long and passes through a glandular structure called the prostate. In elderly men the prostate frequently becomes enlarged and interferes with the passage of urine, so that a catheter has to be used. The membranous urethra is about three-quarters of an inch long, and the spongy portion measures about 5½ inches.

The **inguinal canal,** referred to above, is about 1½ inches in length, and passes obliquely through the wall of the abdomen. It ends at the external abdominal ring immediately above the pubis. The condition called inguinal hernia, so common in male infants and in adult men, consists in the passage into this canal of a portion of bowel, or, less frequently, some other structure.

THE FEMALE ORGANS OF GENERATION

The **ovaries** are two oval organs one of which lies at each side of the uterus. Each ovary consists of a framework of connective tissue containing Graafian follicles. These are round masses of cells one of which is an ovum or egg cell. As the Graafian follicles ripen they rupture on the surface of the ovary and discharge the ova.

The **uterus** or womb is a pear-shaped organ about 3 inches long, 2 inches broad, and 1 inch thick. The large end or

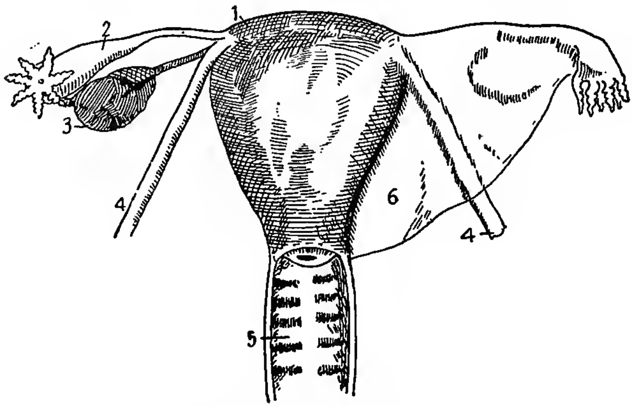

FIG. 61. Female Organs of Generation. 1. Uterus. 2. Fallopian Tube. 3. Ovary. 4. Round ligament. 5. Vagina (opened). 6. Broad ligament.

fundus forms the upper part and is covered by the peritoneum, a fold of which, at each side, forms the *broad ligament*. The lower end or *cervix* projects downwards into the *vagina*. The uterus is composed chiefly of non-striped muscular fibre and connective tissue. It contains a small cavity which is lined by a thick mucous membrane, and opens into the vagina through an aperture called the os uteri. Within the cervix

the mucous membrane is arranged in ridges which produce an appearance known as the *arbor vitæ*.

The **Fallopian Tube** or oviduct is a funnel-shaped tube found in the broad ligament on each side of the uterus into which the narrow end of the tube opens. Each tube is about 4½ inches long. The outer end opens by a trumpet-shaped aperture into the peritoneal cavity. The ripe ova pass through this tube into the uterus. This happens every month, when —unless conception takes place—the greater part of the mucous membrane of the uterus breaks down and escapes with the menstrual discharge.

The *vagina* is a curved tube which lies between the bladder and the rectum. The cervix of the uterus projects into its cavity above. Below it opens in front of the anus, from which it is separated by the perineum. The part where the vagina opens is called the *vulva*. This is bounded at the sides by folds of skin and fat called the *labia*.

The *urethra* of the female is only about 1½ inches in length. About an inch above its opening is a small projection called the *clitoris* which represents the penis of the male.

The inguinal canal is poorly developed. Consequently inguinal hernia is uncommon in women.

CHAPTER XVII

THE SENSES

NERVE currents are continually passing along the afferent nerves to the central nervous system. On such currents consciousness depends. Of some of these currents we are unaware. Some give rise to such sensations as fatigue, restlessness, hunger, thirst. Some, again, are of a more definite character, and are at once judged as due to something outside ourselves. Such are those which come from the organs of special sense, and give rise to the sensations of touch, smell, taste, sight, and hearing. To these we owe our knowledge of the world around us. Hence Bunyan's poetical description of the special senses as the five gates of the City of Mansoul.

These special sensations have their origin in particular parts of the body only. In these parts we find the afferent nerve fibres beginning in particular cells from which the impulses are transmitted along the nerve fibres to the brain.

TOUCH AND ALLIED SENSATIONS

Tactile Sense.—The skin is the special organ of touch. In some of the papillæ of the dermis there are minute oval bodies called *tactile corpuscles.* Each of these consists of the termination of a nerve fibre surrounded by sheaths of fibrous tissue.

Sensitiveness to touch varies greatly in different regions. Experiment upon a friend with a pair of compasses, and find

out at what distance apart he can clearly distinguish the two points when they are simultaneously pressed upon his skin. The usual distances for different parts of the body are as follows:

Tip of tongue	$\frac{1}{24}$ inch.
Tip of forefinger	$\frac{1}{12}$,,
Tip of nose	$\frac{1}{4}$,,
Back of hand	1 ,,
Back of neck	2 or 3 inches.

The sensitiveness of any part of the body can be greatly improved by practice.

Our power of localising a touch also depends on practice, and we easily fall into error if touched in unaccustomed ways. For example, cross the middle and forefinger, close the eyes, and place a pencil between the finger-tips so that it touches them both. You will feel as if there were two pencils. This is because when the fingers are in their customary position it would be impossible for a single pencil to touch the two parts of skin now pressed on.

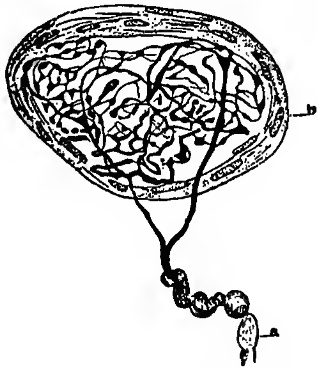

FIG. 62. Tactile corpuscle (after Dogiel).

Temperature Sense.—When heat is withdrawn from the body we have a sensation we call *cold*, and when heat is added we have a sensation we call *hot*. Place one hand in a basin of very hot water, and another in a basin of very cold water. After a minute or two, plunge both hands into tepid water. To the warm hand the tepid water will feel cold, and to the cold hand it will feel warm.

On a cold day a piece of iron feels colder than a piece of wood of the same temperature, because it is a better conductor

of heat, and consequently abstracts heat more rapidly from the skin.

Changes of temperature act on the endings of sensory nerves. If a cold metal point is passed slowly over the skin it will be felt cold only at special spots. By marking these with dots of ink a map of the cold spots may be made. If the point is heated and passed over the skin again, the hot spots may be mapped out in the same way.

Muscular Sensations.—Afferent nerve fibres from the muscles, tendons, and joints convey nerve currents which give rise to the sense of position and of the movement of various parts of the body. We can form some idea of the weight of an object by the pressure it exerts, but we make a more accurate estimate by moving it up and down. This estimate is based on the amount of contraction of the muscles. The nerve current from the contracting muscle causes the muscular sensation.

By the muscular sensation combined with touch we determine the size and shape of objects.

The ability to localise a touch in different parts of the body, the power to judge the consistence of an object or the quality of its surface, the skill to estimate weight and to determine form and size, are all acquired by practice in childhood. The intense desire of all young children to touch and handle whatever they see is the means by which Nature secures the education of the organ of touch, the muscular sense, and the special nerve centres in the brain. The feelings resulting from the handling of various objects is associated with their appearance, and thus the visual centres are also educated. A man blind from birth who recovers his sight after an operation cannot for a considerable time recognise the things he sees unless he touches them also.

TASTE

Taste is a very complex function. What is popularly called

taste includes sensations of touch and smell. Strictly speaking there are only four varieties of taste—sour, salt, sweet, and bitter. Flavour is due to smell, and this is why food loses its flavour when we have a cold in the head. Ask some one to close his eyes and hold his nose tightly. Put a small piece of raw turnip in his mouth and ask him what it is. He will not be able to tell certainly, and will probably accept a suggestion that it is a piece of apple—until he releases his nose!

The Tongue.—The tongue is a muscular organ containing muscles which run across from side to side, and others which run longitudinally. Some muscles pass into the tongue from the hyoid bone, the horse-shoe shaped bone which can be felt in front of the neck above the larynx, and some are attached to the lower jaw. The surface of the tongue is covered with mucous membrane. On the upper surface this membrane is thick, and is raised into papillæ of three varieties. Some—the *filiform* papillæ—are thin and pointed; others, known as the *fungiform* papillæ, are blunt and shaped like a fungus. Both of these varieties are numerous and arc scattered all over the front two-thirds of the tongue. Near the root of the tongue is a V-shaped row of *circumvallate* papillæ (p. 35). These are of large size and each is surrounded by a deep grove or ditch (Latin, *Vallum*).

The tongue is richly supplied with nerves. Some of these are ordinary sensory nerves concerned with touch. The special taste nerves pass to little clusters of cells called *taste buds.* These are most abundant at the bases of the circumvallate papillæ, but are also to be found on the fungiform papillæ and scattered over the surface of the tongue. There are also some on the soft palate and the epiglottis.

Each taste bud is oval in shape, and in its interior are elongated cells with slender hair-like processes. These are the special sense-cells, and it is among them that the taste nerve fibres end.

Before a substance can be tasted, it must be dissolved in order that it may reach the sense cells. If you dry part of your tongue and place some crystals of sugar upon it you will not taste the sugar as long as it remains dry.

The tongue is sensitive to very minute quantities of certain substances. For example, strychnine is the most bitter

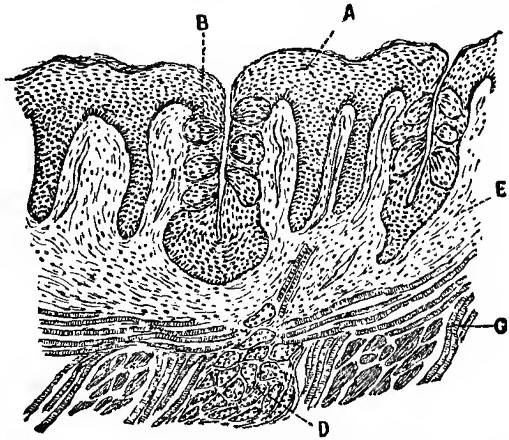

FIG. 63. Microscope, low power. Section through fragment of tongue. A. Stratified layers of cells. B. Taste buds. C. Striated muscle fibres. D. Mucous gland. E. Soft vascular connective-tissue layer.

substance known, and one part dissolved in two million parts of water can be tasted distinctly. We cannot distinguish by taste alone between different kinds of bitters. Strychnine is a deadly poison, but its solution tastes exactly like a solution of quassia, which is harmless. Taste is not a reliable guide to the wholesomeness of food. Occasionally foods which have been kept for a short time (veal, cream, cheese, mussels) become very poisonous without there being any alteration in taste to attract attention.

SMELL

The Nose.—The nasal cavity is divided by the vertical septum into two chambers. The floor of each is formed by the palate, and the roof by the ethmoid bone. From the outer wall project the three scroll-like turbinate bones. The whole of the surface is lined by mucous membrane, which contains numerous blood-vessels and nerve fibres. The lower part of each chamber is the respiratory passage, and the nerve fibres in the mucous membrane are sensitive to any irritating vapour, such as ammonia. In the upper part of the nasal chambers the mucous membrane is thick, and some of the cells at the surface are elongated and bear hair-like processes. These are the special sense-cells for smell. The ethmoid bone is pierced by numerous minute holes, and through these pass the nerves of smell (olfactory nerves), from the special sense-cells to the brain. The nerves of smell are excited by vapour, especially when this is drawn up into the nose by sniffing.

In man smell appears to be a decadent sense. We have a certain amount of pleasure in sweet odours, and we may receive warning of an escape of gas or the proximity of disagreeable substances, but we cannot even imagine what the world must be like to a dog, who guides his actions far more by smell than by sight. Blind children tend to pay more attention to smell than ordinary children, and occasionally a blind child develops an extraordinarily acute perception for odours. It would no doubt be possible in normal children to educate this sense to a much higher degree, but this would for many reasons be a very doubtful advantage.

SIGHT

Sight is a function, not of the eye, but of the brain. The eye is simply the instrument by which we see.

Structure of the Eye.—The **eyeball** is situated in the orbit, and is protected in front by the eyelids. The eyelid is a fold of skin strengthened by a very thin piece of cartilage, and lined by a thin moist mucous membrane called the *conjunctiva*. The eyelashes protect the eye from dust. A stye is due to inflammation at the root of an eyelash.

The white part of the eye is called the **sclerotic**, the front of the eye through which we see is the **cornea**, the coloured portion is the **iris**, and the **pupil** is simply a hole in the centre of the iris.

The **conjunctiva**, after lining the lid, is folded on itself to cover the sclerotic as far as the edge of the cornea. We cannot, therefore, really touch the white of the eye with the finger. There is always a layer of conjunctiva between the finger and the sclerotic.

The tears are secreted by the **lachrymal gland**, which is just under the upper edge of the orbit. The tears bathe the front of the eye and then flow away through two little tubes. If you look at the edge of your lower eyelid in a mirror you will see a little black speck at the corner of the lid near the nose. This is the opening into one of these tubes. It is seen more easily if the lid is drawn down a little by the finger. The opening of the other tube is on the upper lid just opposite. These tubes drain the tears away into a larger tube or duct which opens into the nose. When the tears flow too rapidly to drain away in this manner they overflow on to the cheeks.

To make out the further structure of the eye, it will be necessary to procure one or two bullock's eyes from the butcher. Probably the eyes will be surrounded by a good deal of fat. This must be dissected away. In doing this the student should look for the remains of the muscles which move the eyeball. There are six of these. Four, which are called the straight muscles (*recti*), have their origin from the back of the orbit, and are inserted into the upper, lower, outer,

and inner sides of the eyeball respectively. The other two muscles are called *oblique*, because their tendons pass from the side to the upper and lower aspects of the eyeball. By these muscles the various movements of the eyes are brought about. Over-contraction or shortening of a single muscle causes squint.

When the eyes have been cleaned, one should be cut in two from front to back, and another should be cut across

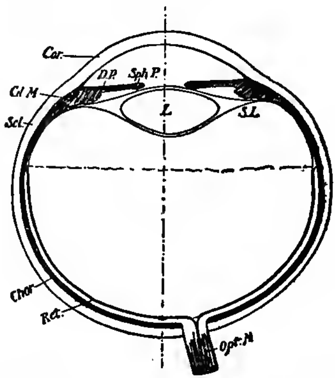

FIG. 64. Horizontal section through the left eye. *Cor.* Cornea. *Scl.* Sclerotic. *Chor.* Choroid. *Ret.* Retina. *Opt. N.* Optic nerve. *L.* Crystalline lens. *S. L.* Suspensory ligament of lens. *Cil. M.* Ciliary processes. *D. P.*, *Sph. P.* Dilator aod Sphincter muscles of the pupil forming part of the Iris. *Cor.* Cornea.

behind the edge of the cornea so as to separate the front part of the eye from the back. This may be done with a very sharp knife or razor, or by means of a pair of scissors after making a small hole for the insertion of one of the blades.

The three coats of the eyeball can be seen by looking at the back half of the eye. The outer coat is the **sclerotic.** It is very tough and forms the entire outer wall of the eyeball except in front, where the outer wall is formed by the transparent **cornea.** The second coat is the **choroid,** which is black owing to the presence of pigment. In the front half of the

eye the choroid can be seen to become thickened and raised into numerous ridges called the *ciliary processes* just within the margin of the sclerotic. Beyond these ridges the choroid is continuous with the *iris*. The third coat is the **retina,** a

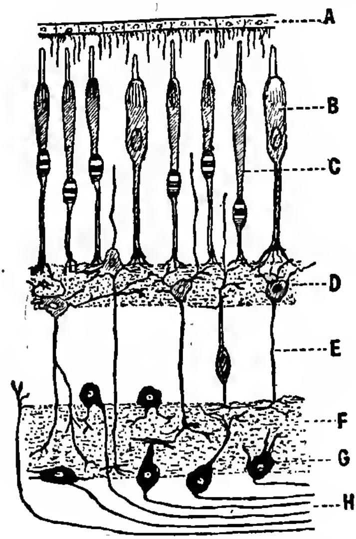

FIG. 65. The retina. Section, highly magnified, showing its various layers, viz.: A. Layer of pigment cells. B, C. Of rods and cones. D, E, F. Of small nerve cells and their processes. G. Of large nerve (ganglion) cells. H. Of nerve fibres passing from ganglion cells to optic nerve. (After Stohr.)

pale delicate membrane which can easily be scraped off the choroid.

At the back of the eye can be found the tough white **optic nerve.** This pierces the sclerotic and choroid and spreads out into the *retina.* The structure of the **retina** cannot be made out with the naked eye, but microscopic examination shows that it is a very complicated membrane composed of several layers, as is represented diagrammatically in Fig. 65. In

the deepest part of the retina (B, C) are curious little bodies called from their shape the rods and cones. They form the sensitive part of the retina. When we look at anything, the rods and cones are stimulated and send messages to the little nerve cells in layer D. These pass the messages on to the big nerve cells (G) in layer F, and these again pass on through the fibres of the optic nerve (H) to the brain.

Now examine again the front of the eye. The pupil of the ox is oval, not round as in man. The **iris** is composed of two layers of muscle—a circular layer whose contraction diminishes the size of the pupil, and a radially arranged layer whose contraction dilates it. The colour of the eye depends upon the amount of pigment in the iris.

Just behind the iris lies the crystalline **lens**—a thick biconvex lens contained within a thin capsule. This capsule is adherent all round to the ciliary processes, and as it moors the lens in place, it is called the suspensory ligament of the lens.

Between the lens and iris and the cornea is a small space called the anterior chamber. In this is a watery fluid, the **aqueous humour.** The large space behind the lens is filled with a perfectly clear jelly, the **vitreous humour**.

A ray of light falling upon the eye passes through the cornea, the aqueous humour, the pupil, the lens, the vitreous humour, and falls on the retina. If the ray passes through the centre of the cornea and of the lens it will fall on the most sensitive part of the retina, which is called the yellow spot. The optic nerve enters the eye on the inner side of the yellow spot.

The Physiology of the Eye.—The eye is practically a little camera. The sclerotic is the box, the choroid is the black lining which prevents the reflection of light, and the retina is the sensitive plate. The iris is a stop which regulates the amount of light which enters the eye. In a dim light the pupil dilates, in a bright light it contracts. The crystalline lens forms the image upon the retina. Just as the lens of a

camera forms an inverted image upon the sensitive plate so the lens of the eye forms an inverted image of the object looked at on the retina.

Accommodation.—When we turn our gaze from a distant to a near object we are conscious of some change within the eye before we see the near object clearly. This change is called accommodation for near vision. It occurs in the following way:

The rays of light which fall upon the eye from a distant object are parallel, those which come from a near object diverge

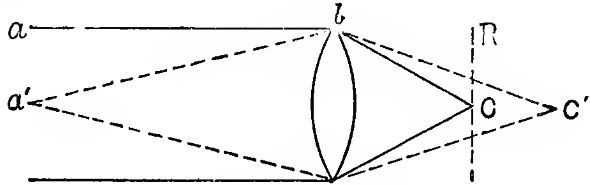

FIG. 66.

more and more the nearer the object is brought to the eye. The diagram shows that when parallel rays of light are bent by the lens so as to be brought to a focus on the retina (R), diverging rays cannot be brought together so quickly, for the angle *a b c* is equal to the angle *a′b c′*. Their focus is, therefore, behind the retina. On the retina they form a blurred image. To obtain a clear image of a near object, either the distance between the sensitive surface and the lens must be increased, or a stronger lens must be used. The former plan is made use of in the case of a camera, whose lens can be screwed back and forward. It is the latter plan which nature has adopted for the eye. Whenever we look at a near object a little muscle which is attached to the suspensory ligament of the lens contracts and pulls upon the capsule. Now the capsule is rather tight and normally compresses the lens. When it is pulled upon in this way it relaxes, and the lens bulges forward by its own elasticity, and so becomes more

convex. The rays of light, passing through a more convex lens, are bent to a greater degree and so are brought to a focus farther forward, and thus a sharp image is formed on the retina.

Convergence.—When the gaze is directed on a near object the eyes converge, as may be seen, to take an extreme in-

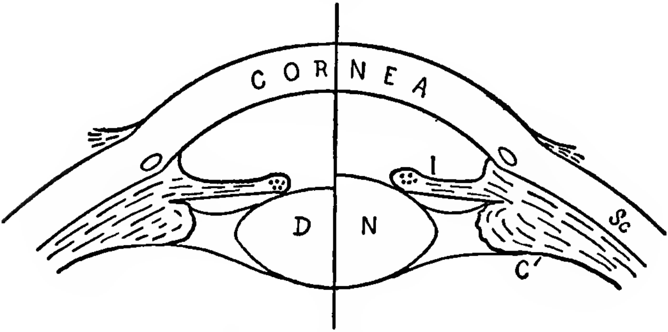

FIG. 67. Accommodation, showing the changes in the lens when focussing a distant (D) or a near (N) object. I. Iris. C. Ciliary process. Sc. Sclerotic.

stance, when one looks at the tip of one's nose. This convergence has two effects.

First, it is chiefly by the feeling of effort which is associated with convergence that we judge of the distance of objects. It is much more difficult to judge distance when one eye is shut. When one eye is shut, we judge distance by the effort of accommodation only. The distance of distant objects is judged by their apparent size and the amount of intervening country.

Secondly convergence leads to the image being formed on corresponding parts of the two retinæ. If the images were not on exactly corresponding parts of the retinæ we should see double. This can easily be shown by experiment. Look at something and press lightly on the globe of one eye. With the least displacement of the eye the object appears double. Whenever we look at a near object, the convergence

of the eyes necessarily results in the images of distant objects ceasing to correspond, and the only reason they do not appear double is that they are a little out of focus, and we are paying no attention to them. But that they are doubled can be shown in this way. Hold up one finger about four inches in front of the eyes, and another in line with it at arm's-length. Look at the near finger and the distant one will seem double.

Note the association between accommodation and convergence. The nearer an object is, the greater the accommodation necessary to see it, and the greater the effort of convergence.

Errors of Refraction.—The normal eye may be defined as one in which distant objects are focussed on the retina without accommodation; or as one in which parallel rays of light are focussed on the retina when the eye is at rest. The rays of light which fall on the lens from a point twenty feet away are practically parallel. A distant object therefore is one which is twenty feet or more from the eye.

The Hypermetropic or Flat Eye.—It is not uncommon, especially in early childhood, for an eye to be too short from front to back. In such a case parallel rays of light would be focussed by the lens behind the retina. We have already seen that the normal eye *at rest* focusses near objects behind the retina. The hypermetropic eye, therefore, to see distant objects must do what the normal eye does to see near objects; that is to say, it must accommodate. And if it must accommodate to see distant objects, it must accommodate excessively to see near objects. This excessive accommodation is necessarily associated with excessive convergence. A child with hypermetropia, therefore, runs the risk of two dangers—strain of the eye from excessive accommodation and squint from excessive convergence. These dangers are to be averted by the avoidance of unnecessary near work, and by wearing suitable spectacles, as shown in Fig. 68.

The Myopic or Long Eye.—This is the condition commonly

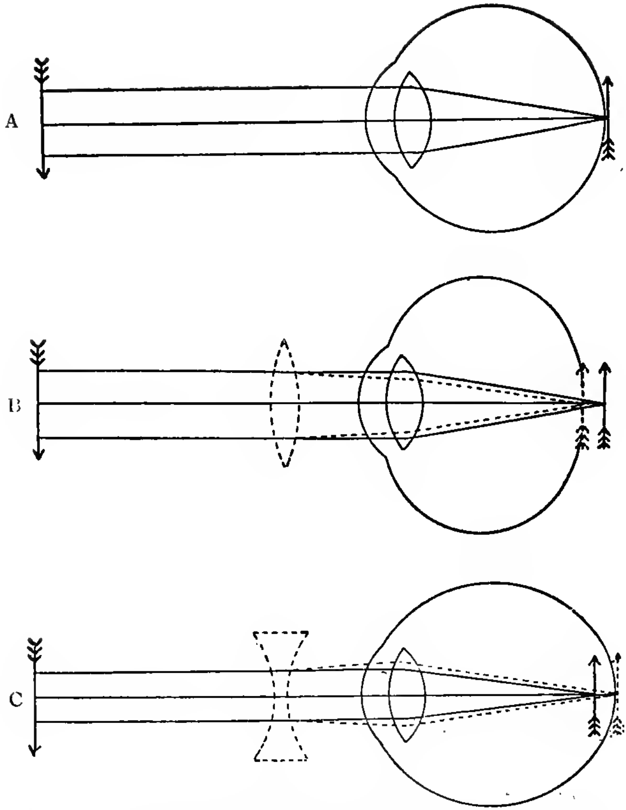

FIG. 68. A. The normal eyeball, in which, when the ciliary muscle is relaxed, parallel rays are brought to a focus on the retina. B. A hypermetropic eyeball. Its depth being less than normal, parallel rays are not brought to a focus on the retina when the eye is adjusted for distant vision without the aid of a convex glass. C. A myopic eyeball. Its depth being more than normal, a concave lens is needed to diminish the convergance of parallel rays. (From Alex. Hill's "Body at Work.")

called short-sight. It is the opposite of the last. The distance of the retina from the lens is too great, and therefore distant objects are focussed in front of the retina and cannot be seen clearly. Near objects can be seen clearly and with less accommodation than in the case of the normal eye. It is not common in young children, but develops later. Excessive near work tends to produce it.

Astigmatism.—Another common fault in the eye is that the cornea, or rarely the lens, is not curved equally in all directions. The result of this is that a distorted image is produced. This condition is called astigmatism. Some idea of the kind of effect produced by such unequal curvature may be gained by examining your reflection in the bowl of a spoon. Astigmatism, unlike short sight, is not liable to get worse, but it often causes unpleasant symptoms, such as headache. People who suffer much from headache should have their eyes carefully tested.

Presbyopia.—In old age the lens becomes less elastic, and consequently accommodation becomes less efficient. The old man may see distant objects clearly, but he requires to hold his book farther and farther from his eyes, until at last he cannot read it even at arm's-length. The defect in the lens may, however, be remedied by wearing magnifying spectacles.

The Blind Spot.—The retina is insensitive at the entrance of the optic nerve. There is here, consequently, a blind spot. To demonstrate this, mark a dot and a cross on a piece of paper, thus:

● +

Close the left eye and look steadily at the dot. Hold the paper at a distance from the eye and bring it gradually nearer. At a certain point the cross will disappear, to reappear when the paper is brought nearer still.

Judgment of Solidity.—We have seen that the images formed on the retinæ must correspond in position, otherwise

we see double. But the images need not be, and in the case of solid objects are not, exactly alike. This can be demonstrated by looking at an object and closing first one eye and then the other. The appearance of solidity is a judgment based upon the difference in the images. The effect of solidity and distance produced by the stereoscope is due to slight differences in the two photographs, which therefore produce differing images on the retinæ.

Colour Sensation.—The sensation of light is due to the stimulation of the retina by vibrations of the ether. Colour sensation is due to varying rates of vibration. The less rapid vibrations are invisible. As the vibrations become more and more rapid they cause the sensations of red, yellow, green, blue, and finally violet light. If a beam of sunlight is made to shine upon a sheet of white paper through a glass prism the different colours are separated from one another and a rainbow of colours called the spectrum is formed on the paper.

The colours of objects are due to the fact that they absorb certain parts of the spectrum, and reflect or transmit others. Thus a violet appears blue because it reflects the blue rays, and absorbs all the rest. As the light fades, objects gradually lose their colours. A scarlet geranium, for instance, becomes dull red, maroon, brown, and finally black. In the dark, grass is no longer green. A white surface reflects almost all the vibrations, a black surface almost none.

By mixing different parts of the spectrum, white or some intermediate colour may be produced. This may be done by spinning a top which has been painted with different colours. To produce the sensation of white we do not require to mix all the colours of the spectrum. Certain pairs of colours called *complementary* produce the same effect. The following are examples:

Red and green-blue.
Orange and blue.
Green and pink.
Yellow and indigo blue.

It is to be noticed that the effect of thus mixing coloured lights or coloured reflections is quite different from the effect of mixing coloured paints.

Complementary colours can be demonstrated in another way. After staring steadily at one of these colours look suddenly at a sheet of white paper, and the complementary colour will be seen.

Colour Blindness.—Some people are unable to discriminate colours. The degree of this defect varies and it is rarely absolute. The most common form is a confusion between red and green. About one man in thirty is affected in this way, but among women the defect is rarer. Curiously enough, colour-blind people are often quite unaware of their peculiarity. They may even name the colours of objects correctly. This is because they *know* that grass is called green, and that a dark *rose* is called red. The difference between the rose and the grass is, to them, a difference of shade only, and they suppose that this is so with every one else.

The usual test for colour blindness is to give a person a piece of red wool and ask him to pick out from a large number of skeins of wool, all those of the same colour, whether lighter or darker in shade. The colour-blind person will include some shades of green in his selection. The condition is obviously of great importance to engine drivers and seamen.

The Visual Centre in the Brain.—When an image is formed on the retina a nerve current passes through the optic nerve to the brain and stimulates the nerve cells in the centre for vision (Fig. 78). There is a centre for vision on each side of the brain. These centres do not correspond to the two eyes, but each centre is connected with both eyes. If one centre were destroyed half of each retina would be blind, and we should be unable to see to one or other side.

The fact that, although the image on the retina is inverted, we do not see things upside down, is due to the fact that we associate "up" with a stimulus coming from the lower part of

the retina, and "down" with a stimulus coming from the upper part.

The visual centre of the left side seems to be specially concerned in the storing of visual memories. We have already seen that destruction of the small visual speech centre would render us unable to read. If the destruction involved the whole of the left centre for vision, we should still see objects, but we should fail to recognise them. But we might discover what they were by handling them.

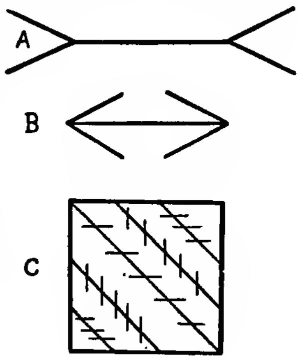

FIG. 69. Illusions.

Vision being a function of the brain, perception implies the formation of judgments of what we are looking at. Such judgments are based on experience. Keenness of perception can be greatly increased by practice.

Erroneous visual judgments are common. For example, a white disc on a black ground looks larger than a black disc of the same size on a white ground. Again, in Fig. 69, the horizontal line in A looks shorter than the corresponding line in B, whereas it is the same length. In C the diagonal lines are really parallel, but they do not appear so.

One or two other familiar examples of visual illusions may be mentioned. When we are driving in a carriage distant objects in the landscape often appear to be moving in the same direction. When we watch the moon through swiftly moving clouds, our eyes often tell us that it is the moon which moves. When we are sitting in a stationary railway carriage and see another train move off, we often imagine that it is our own train which is starting. When we watch the sun setting, the sun's disc appears to grow larger as it approaches the horizon.

Vision in Childhood.—Infants cannot see clearly until they learn to focus accurately. This art is acquired very early, but every one must have noticed how easily an infant loses sight of a moving object. For a long time after children have learned to focus sharply and to move their eyes quickly and accurately, they are extraordinarily prone to form erroneous visual judgments similar to the illusions just referred to. Hence the natural tendency of children to amplify their visual impressions by an appeal to their other senses. The child's instinctive efforts to touch and handle whatever he sees should be gratified as far as possible. It is by this means that experience is gained. Young children should be allowed to examine and play with a large variety of common things, but they should also be trained to look at and describe distant objects, in order that they may gain experience in judging form, size, and distance.

SOUND

Sound is produced by rapidly vibrating bodies. When a tense string is twanged we can see the vibration. If the vibrations occur rhythmically the sound is musical. As the sound dies away the vibrations become smaller—the loudness of the sound depends on the amplitude of vibration. If the vibrating string is shortened the vibration will become more rapid and the pitch of the note will become higher. The lower pitch of a man's voice as compared with a woman's depends on the greater length and consequently slower vibration of his vocal cords.

Sounds differ not only in loudness and in pitch, but in quality. The quality of a sound depends upon the form of the wave.

The transmission of sound depends upon the elasticity and density of the air. The rate of transmission is enormously slower than that of light, being only 1100 feet per second.

Thus one may judge the distance of a storm by the time which elapses between the flash of lightning and the roll of thunder. Sound may also be transmitted through walls or through solid bodies, and in either case the rate of transmission is considerably greater than through air.

A tuning-fork or a stretched string when vibrating can set in vibration a neighbouring fork or string which is set to the same note. Such sympathetic vibrations can also be set up in the wires of a pianoforte by singing a note.

The human ear is said to distinguish notes varying from 20 vibrations per second to 40,000 per second, but individuals vary greatly in this respect. Many people are unable to hear the high pitched squeaking of a mouse or a bat.

HEARING

The Ear.—The ear consists of three portions: outer, middle, and inner.

The External Ear.—The auricle or flap of the ear is a fold of skin strengthened by an irregular sheet of cartilage. In its deepest part is a hole, which leads into a passage called the **external auditory meatus.** This passage is about an inch long, and ends at a thin membrane which separates it from the middle ear. The membrane is called the drum of the ear, or **tympanic membrane.** At the entrance to the passage are a few hairs, which obstruct the entrance of insects. The skin in the passage contains glands which secrete wax. Sometimes this wax accumulates to such an extent as to block the passage, and deafness results. In children the passage is sometimes blocked by some object such as a pea, which the child has pushed in. Under such circumstances no attempt should be made to clear the passage by picking lest the drum be injured. The proper way to remove the obstruction is to syringe with warm water.

Many of the lower animals can move the auricle freely, the

better to catch the waves of sound. It is a curious thing that the muscles for moving the ear are present in man, though the power to move the ears has practically disappeared.

The Middle Ear.—The middle ear is a small but important cavity in the temporal bone. In size it is about a quarter of an

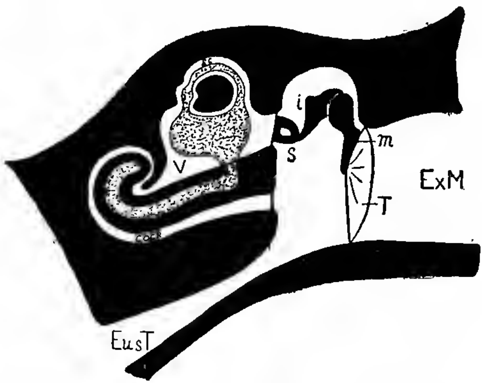

FIG. 70. Diagram of structure of ear much simplified. Ex.M. External auditory meatus. T. Tympanic membrane (ear-drum). m, i, s. Malleus, incus, and stapes, in middle ear. S.c. Semicircular canal. V. Vestibule. Coch. Cochlea. Eus.T. Eustachian tube. The brain lies above the bone, which is represented in black.

inch from front to back. Its outer wall is formed chiefly by the tympanic membrane. Above, it is separated from the cranial cavity and the brain by a very thin plate of bone. Behind, it opens into the largest of the numerous little cavities in the mastoid portion of the temporal bone. In front and below, it opens into the **Eustachian tube.** On its inner wall are two little holes, one round and the other oval. These are called respectively the *fenestra rotunda* and the *fenestra ovalis.* Each hole is closed by a membrane which separates the middle from the inner ear.

The **Eustachian tube** has been mentioned already as passing from the middle ear to the pharynx. It is a tube about an

inch and a half long. Its upper part is of bone, its lower of cartilage, and it is lined by mucous membrane. Ordinarily its walls are in contact so that the passage is closed, but during the act of swallowing the contracting muscles pull upon the tube and open it so that air can pass between the pharynx and the middle ear. If you take a sip of water, puff out your cheeks so as to increase the air pressure, and then swallow the water, you will probably feel some fulness in the ears, owing to an excess of air having been forced up the Eustachian tube. Upon swallowing again the sense of fulness will disappear.

Inflammation in the throat is apt to spread up the Eustachian tube and earache results. Sometimes matter forms in the middle ear and makes an outlet for itself through the tympanic membrane. This is what has happened when a child has "a running ear." This condition should always be under treatment, because there is a risk not only of deafness, but of the spread of the inflammation to the mastoid cells or to the brain, probably with a fatal result.

Stretching across the middle ear is a chain of little bones. The outermost of these, called the **malleus** (*hammer*), is attached to the tympanic membrane. To it is attached the **incus** (*anvil*). To this again is attached the **stapes** (*stirrup*). The stapes is shaped just like a stirrup, and the plate of the stirrup fits into the fenestra ovalis where it is attached to the membrane that fills it. When the drum of the ear is set in vibration oy a sound, the vibrations are conducted across to the membrane in the oval fenestra by this chain of little bones. These bones are so ingeniously connected together that they can conduct the slight vibrations of the tympanic membrane produced by a low sound practically without loss, but if a very loud noise set the tympanic membrane in violent movement, the violence of the vibrations is greatly reduced before they reach the fenestra ovalis, and thus the delicate structures of the inner ear which lie within are saved from injury. There

is also a little muscle inserted into the stapes which helps to damp loud sounds.

The Inner Ear.—The inner ear includes the bony and the membranous labyrinth.

The **bony labyrinth** consists of the vestibule, the cochlea, and three semicircular canals (*see* Fig. 70). The **vestibule** is the central chamber out of which the cochlea and the semicircular canals open.

The **cochlea** is a tube which is coiled on itself two and a half times, so that it looks like a snail's shell. A plate of bone projects into the cochlea and partially divides it, through its whole length, into two tubes. The division is completed by a membrane called the *basilar membrane.* One of these tubes begins at the fenestra ovalis and winds round the cochlea to its apex. There it opens into the other tube, which winds down again and ends at the fenestra rotunda. The course which has just been described is that which is taken by waves of sound. The bony labyrinth contains a fluid called perilymph. When a sound sets the membrane in the fenestra ovalis in vibration, the vibrations are communicated to the perilymph and pass up the one canal of the bony cochlea and down the other.

The **semicircular canals** are three in number, one horizontal and two vertical. Each canal has a little swelling at one end called its ampulla.

The **membranous labyrinth** in general conformation resembles the bony labyrinth, to which it forms a kind of loose lining. It is, however, considerably smaller, and the space between the membrane and the bone is filled with the perilymph. The membranous labyrinth itself is full of a fluid called endolymph. The part of the membranous labyrinth in the vestibule is divided by a deep groove into two portions called the *utricle* and the *saccule.* Out of the saccule there springs the membranous cochlea. This passes into the bony cochlea and winds round to the apex, where it ends blindly. It lies upon

the basilar membrane; and forms a third channel between the two which have been already described. In this membranous cochlea is a very complicated structure called the *Organ of Corti*.

The **organ of Corti** is to the ear what the retina is to the eye. It rests upon the basilar membrane and consists essen-

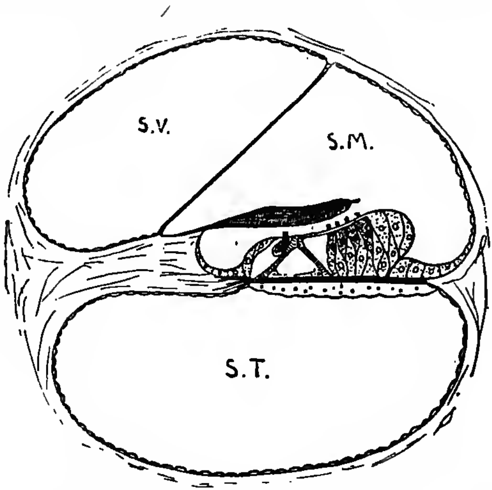

FIG. 71. Cross-section through one turn of the cochlea to show the organ of Corti on the basilar membrane (magnified). S.V., S.T. The two passages in the bony cochlea. S.M. The membranous cochlea.

tially of two parts—a little tunnel formed of about 3000 arched posts, and of some 17,000 to 20,000 cells called hair cells, because a fringe of hair-like processes projects from them. It is to these cells that the fibres of the auditory nerve can be traced. Over the hair cells there rests a fine membrane which is believed to act as a damper.

From the utricle a *membranous semicircular canal* extends into each of the bony canals. Each of these is provided with an ampulla.

The **auditory nerve** or nerve of hearing consists of two

parts. The larger portion passes to the cochlea and its fibres can be traced to the hair cells or the organ of Corti. These fibres are specially concerned with hearing. The nerve currents which are set up in the organ of Corti are conveyed by them to the brain and reach the auditory centre in the cerebral cortex.

The other portion of the auditory nerve passes to the semicircular canals. These canals make us aware of sudden changes in position. When we move our head in any direction the endolymph in some of the canals (according to their position) tends to lag behind. It thus presses upon hair cells which are situated in the ampullæ. A nerve current is set up and passes to the brain. Disease of the semicircular canals causes giddiness, noises in the head, and a reeling gait.

Recapitulation of the Course of Sound Waves.—When a sound sets the tympanic membrane in vibration, the vibrations are conveyed across the middle ear to the membrane of the fenestra ovalis by the chain formed by the malleus, incus, and stapes. Thus the perilymph of the inner ear is set in motion and the waves of vibration pass in all directions. Some pass up one canal of the cochlea to its apex and descend by the other to the vestibule opposite the fenestra rotunda. Others pass to the semicircular canals. These vibrations affect the membranous labyrinth and waves are produced in the endolymph which affect especially the organ of Corti, from whose hair cells nerve currents are sent up the fibres of the auditory nerve to the brain.

CHAPTER XVIII

THE NERVOUS SYSTEM

THE **Nervous System** comprises the nerves, the spinal cord, and the brain.

The Nerves.—Nerves pass from the brain and spinal cord to all parts of the body. Twelve pairs of nerves called cranial come from the brain and pass through holes in the skull. Thirty-one pairs of nerves spring from the spinal cord and pass out of the spinal canal through apertures between the vetebræ. Nerves vary greatly in size. They are largest near their origin from the brain or cord. As they pass to their distribution they divide into smaller and smaller branches, and at last end in minute twigs which are invisible to the naked eye. The larger nerves look like white cords. The largest nerve in the body, the sciatic nerve in the back of the leg, is about as thick as a finger.

Nerves are composed of fine threads or fibres. In a large nerve these fibres are arranged in strands or bundles which separate from each other as the nerve breaks up into branches. The individual nerve fibres are very thin, as they measure only $\frac{1}{4000}$ inch in thickness. Under a microscope a nerve fibre is seen to consist of a central core, which is called the **axon**, a layer of white fatty material which forms a **white sheath** around the axon, and, outside this again, a very thin **gray sheath** of connective tissue. A model of the structure might be made by wrapping a candle in a sheet of paper. The axon is the most important part of the nerve fibre. Although so thin it may be of great length. Each axon extends un-

broken through the whole length of the nerve fibre to which it belongs. The longest nerve fibres in the body are those which extend from the spinal cord to the tips of the toes.

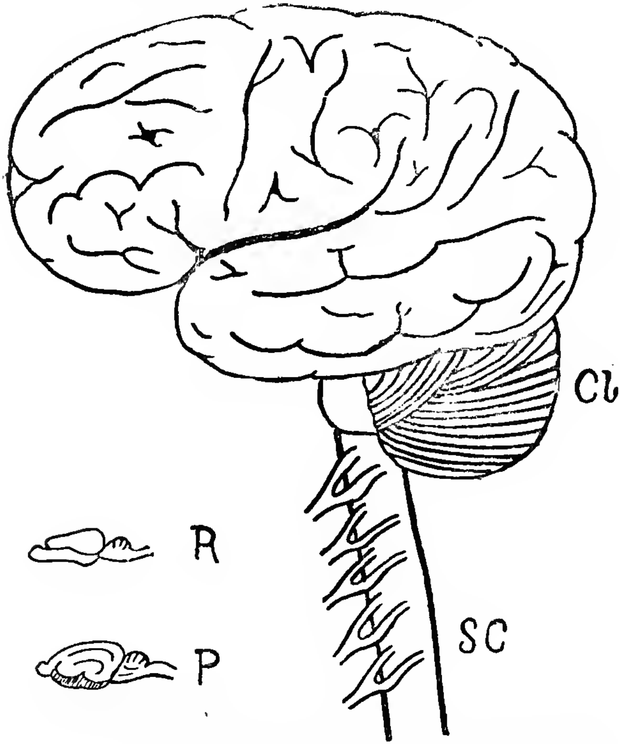

FIG. 72. The brain. C. Cerebrum. Cb. Cerebellum. S.C. Spinal cord. R. Brain of rabbit, and P, brain of pig, to show the amount of convolution, but not the relative sizes.

Nerves are the telegraph wires of the body. Their function is to carry messages from one part to another. We may divide nerve fibres into two classes—**efferent**, which carry messages from the brain or cord to the muscles (motor fibres), or to glands (secretory fibres); and **afferent**, which carry

messages from the sensitive parts of the body to the brain or cord. In some nerves all the fibres are efferent (for example, the facial nerve, whose fibres pass to the muscles of the face); in some (such as the nerve of sight) they are all afferent. In the spinal nerves and some of the cranial nerves there are both efferent and afferent fibres. The spinal nerves come from the sides of the spinal cord. Each nerve arises by two roots, an anterior and a posterior, which join together. Just before the junction there is a little swelling called a ganglion on the posterior root. It is a very interesting and important fact

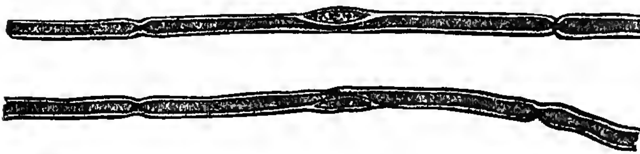

FIG. 73. Pieces of two white nerve fibres.

that all the fibres in the anterior roots are efferent (chiefly motor), while the fibres in the posterior roots are afferent (sensory). (*See* Fig. 74.) If the anterior roots of the nerves which go to the leg were cut across, the leg would be paralysed, but it would still be sensitive. On the other hand, if the posterior roots were cut, there would be complete loss of sensation in the limb, but the muscles would retain their activity. Hence the anterior root is usually called the motor root, and the posterior root the sensory.

If an exposed nerve is pinched, or irritated by a hot wire, or an electric shock, the muscles to which the nerve is distributed contract. This indicates the passage of a nervous impulse along the nerve. What the nature of this impulse is we do not know. It passes along the axon. The white sheath serves the same purpose as the insulating material in a telegraph cable. It prevents the nervous current from escaping from one axon to another.

The Distribution of the Nerves.—The twelve pairs of *cranial* nerves arise from the base of the brain in the following order:

I. Olfactory or nerve of smell, distributed to the nose.
II. Optic or nerve of sight.
III. Oculo-motor, to the muscles which move the eye except the superior oblique and the external rectus.
IV. Patheticus to the superior oblique muscle of the eye.
V. Trigeminal or sensory nerve to the face.
VI. Abducens to the external rectus muscle of the eye.
VII. Facial or motor nerve to the face.
VIII. Auditory to the ear.
IX. Glossopharyngeal, a sensory nerve to the tongue and pharynx.
X. Pneumogastric or Vagus (Latin, "wandering"), a long nerve which gives off branches to the larynx, lungs, heart, stomach, etc.
XI. Spinal-accessory to muscles of the back.
XII. Hypoglossal or motor nerve to the tongue.

The *spinal* nerves escape from the spinal canal through the intervertebral foramina. Each nerve, as it emerges, gives off a branch which turns back to be distributed to the skin and muscles of the back. The main trunk of the nerve passes forward. The dorsal nerves pass between the ribs and become the intercostal nerves. The cervical nerves and the lumbar and sacral nerves divide into branches which join one another so as to form networks or plexuses. The nerves of the arm are derived from the cervical plexus; those of the leg from the lumbo-sacral plexus. The result of this arrangement is that the large nerves which enter the arm and leg do not correspond to particular spinal nerves, but each of them contains fibres derived from several spinal nerves.

The Spinal Cord.—The spinal cord lies in the spinal canal.

It extends from the brain to the upper part of the lumbar region. In the child it extends rather further. It does not fill the spinal canal as it is only about half an inch in thickness. In two places it is slightly swollen—where the large nerves for the arms and for the legs are given off. The cord is closely covered by a thin membrane called the **pia mater**, and the spinal canal is lined by a strong membrane called the **dura mater**. Between these two is a very delicate membrane

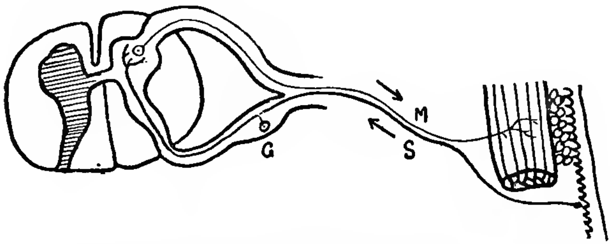

FIG. 74. Section of spinal cord, illustrating reflex action. S. Sensory nerve fibre from skin. G. Ganglion on posterior root of nerve. M. Motor nerve fibre from nerve cell in gray matter of cord to muscle.

called the **arachnoid**. The space between the membranes is filled with a watery fluid called **cerebro-spinal**, because it is found in the head also, both within the brain and between the membranes surrounding the brain. But the brain fills the skull so accurately that there is not nearly so much room for fluid as in the spinal canal. The cord is moored in its place by the spinal nerves and also by bands of ligament, and these along with the packing of fluid protect it very securely from shock or jar.

If the cord is cut across with a sharp knife it is seen to be composed of two substances—white and gray. The **gray matter** is in the centre of the cord. In cross-section it is shaped like the letter H. The upper parts of the H are directed towards the front of the cord, and are called the anterior horns of the gray matter. The lower parts are called the posterior horns. They are smaller than the anterior. In

the bridge connecting the two halves of the H is a minute aperture, visible with a lens. This is due to a fine canal which runs through the whole length of the spinal cord.

The **white matter** of the cord closely resembles a nerve in its minute structure. The white appearance is due to the white sheaths of the nerve fibres which pass through it.

The **gray matter** is quite different in structure. It also contains nerve fibres, but these have no white sheath. In addition to nerve fibres we find what are the most important structures in the nervous system, namely, **nerve cells.** Nerve cells are not absolutely confined to the gray matter of the brain and cord, as some are present in such ganglia as have been mentioned in connection with the sensory nerve roots, and in a few other places, such as the retina.

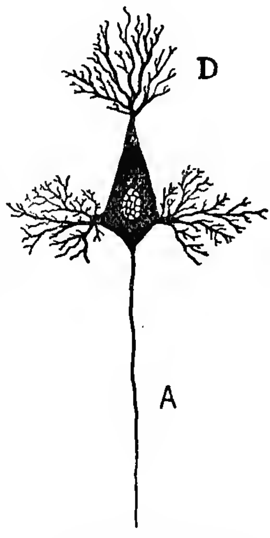

FIG. 75. Nerve cell with nucleus D. Dendrites. A. Axon.

Nerve cells resemble other cells in that they are little masses of protoplasm, each with a nucleus in its interior. The most remarkable fact in the obvious structure of the nerve cells is their relation to the axons of the nerves. *Every axon can be traced to one particular nerve cell.* Indeed we must look upon the axon as being part of the nerve cell, a process of the cell enormously long, though extremely attenuated.

The largest nerve cells are found in the anterior horn of the gray matter. The axons of these cells can be traced into the anterior or motor roots of the spinal nerves. Hence these cells are called the *motor nerve cells* of the spinal cord. Each cell

gives off, besides an axon, a number of short processes called **dendrites** which branch like trees in the gray matter. The interlacing branches of neighbouring dendrites form a regular feltwork. In the posterior horns the nerve-cells are fewer and smaller. Their axons do not pass out of the cord itself.

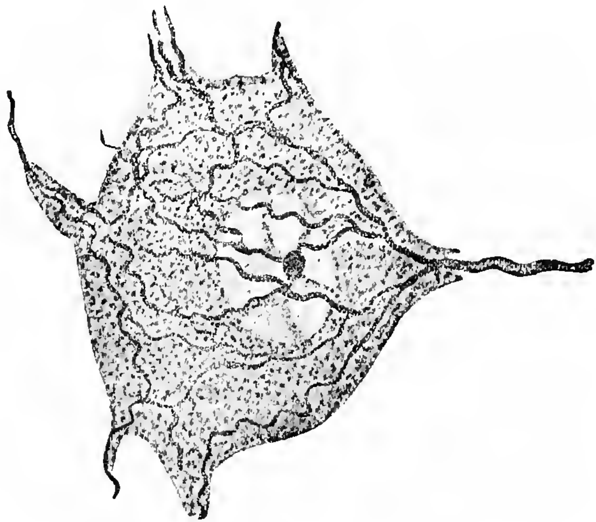

FIG. 76. Nerve cell, very highly magnified.

The axons of the sensory nerve fibres are connected with nerve cells in the ganglia on the posterior roots. Each of these cells gives off an axon which divides into two branches. One of these is an axon of a sensory nerve fibre which passes down the nerve to the end of one of its twigs, while the other passes up into the cord, where it gives off branches which help to form the felt-work of gray matter (*see* Fig. 74).

The Brain.—The brain consists of the cerebrum, the cerebellum, the pons, and the medulla.

The **medulla** is the upward continuation of the spinal cord.

The **pons** is composed of nerve fibres passing across from one half of the cerebellum to the other.

The **cerebellum** or little brain lies underneath the hinder part of the cerebrum. It is divided by a deep cleft into a right and a left half, and its whole surface is thrown into folds. Each half is connected by a band of nervous matter with the medulla below, and by another band with the cerebrum above, while, as has just been mentioned, the two halves are connected by the fibres of the pons.

The nervous matter of the spinal cord can be traced right up through the medulla, and then between the pons (whose fibres embrace it) and the cerebellum, into the cerebrum.

The **cerebrum** forms the greater part of the brain. It is divided by a deep cleft into the right and left cerebral hemispheres, and its entire surface is thrown into folds called convolutions between which are grooves or fissures. At the bottom of the cleft between the hemispheres is a strong band of nervous tissue called the *corpus callosum*, which connects one hemisphere with the other.

The Gray Matter of the Brain.—Like the spinal cord the brain is composed of white and gray matter, but the arrangement is somewhat different. We can trace the central gray matter of the cord right up through the medulla, and pons, to the base of the brain. In the medulla the gray matter becomes more abundant, and here and in the pons it is somewhat cut up by strands of white nerve fibres which pass through it. This division is still more marked in the base of the brain, for there the gray matter is broken up into a number of separate masses of considerable size called the **basal ganglia**. These ganglia are embedded in the white matter of which the bulk of the brain is composed. This great mass of white matter can be very well displayed by cutting through the brain (Fig. 79). Such a section also shows that the entire surface of the brain is covered by a thin layer of gray matter which clothes the convolutions and dips down to the bottom of all the

fissures between them. This is called the **cortex** of the brain.

As is the case in the cord the gray matter of the brain contains nerve cells and a feltwork of their processes. The highest functions of the brain depend upon the nerve cells of the cerebral cortex. These cells are extremely numerous. By counting the cells in thin slices of the gray matter it has been calculated that their total number is about 3,000,000,000. If the gray matter could be stripped off the surface of the brain and spread out flat it would cover a wide area. The folding of the cortex enables this extraordinary number of nerve cells to be accommodated within the skull. The more intelligent an animal is, the greater must be the complexity of the structure of the brain, and the greater the folding of the surface. In the higher apes the brain is much simpler than that of man, but it is well convoluted and the principal folds of the human brain can be recognised. The brain of the dog is much less richly convoluted than that of the ape, while in such animals as rabbits and guinea-pigs convolutions are almost absent.

FIG. 77. Section of gray matter of cortex of brain, showing the nerve cells.

The size of the brain is important relatively to the size of its possessor. The average weight of a man's brain is about three pounds. The brain of a woman is about four or five ounces less. The brain of a good-sized crocodile is not much larger than a man's finger. It has been calculated that the gray matter of the cortex of the human brain has a total area of about 340 square inches.

THE FUNCTIONS OF THE NERVOUS SYSTEM

The Spinal Cord.—The great function of the spinal cord is **reflex action**, of which the following are examples: the jerking away of the hand when it accidentally touches something hot; the withdrawal of the foot when the sole is tickled; the sudden closing of the eye when anything threatens to touch it; the contraction of the pupil before a bright light; sneezing; coughing; swallowing (*see* Fig. 74).

Taking the first as an example, what happens is that (1) a message passes up the sensory nerve fibres from the skin to the spinal cord; (2) this message passes into the gray matter of the cord, reaches the motor nerve cells, and causes them (3) to send a current down the motor nerve fibres to the muscles, which are thereby stimulated to contract. In every reflex act we find these three parts—the sensory message, the nervous discharge, and the effect of the latter.

The effect, however, is not always a movement. When, for example, our mouth waters at the sight of food, the effect of the nervous discharge is the stimulation of the salivary glands. The amount of blood flowing to a part may also be affected reflexly, for example, in blushing.

Many reflex movements can be carried out from the time of birth, but there are others which are acquired subsequently. Indeed any movement or series of movements which we learn to perform, no matter with what difficulty, will come in time to be carried out reflexly with a minimum of attention on our part. Walking, dancing, cycling, knitting may serve as examples. A woman may continue knitting although giving no attention to what her hands are doing. But she could not do this if her hands lost their feeling, because the successive movements are regulated by a succession of sensory messages. Acquired reflexes of this kind are commonly spoken of as **automatic movements.**

The Medulla.—Although the medulla is usually described

as forming part of the brain, its functions are akin to those of the spinal cord. The gray matter of the medulla, which is the upward continuation of the gray matter of the cord, contains the nerve cells which are concerned in many important reflex movements. Indeed this is also true of the other gray matter in the base of the brain. It is in this gray matter that the nerve cells are situated, which serve as nerve centres for such reflexes as the contraction of the pupil and the winking of the eye, and such automatic movements as take place in chewing. More important than these are the nerve centres concerned in regulating the movements of respiration and of the heart. These centres are situated in the medulla.

The respiratory centre furnishes a good example of the fact that some nerve centres may be excited in a variety of ways. A dash of cold water on the chest will cause a sudden gasp. This is reflex movement. We can breathe more rapidly or hold our breath for a limited period at will. This is voluntary movement (*see* p. 181). But the stimulus to which the respiratory centre is most susceptible is the carbonic acid in the blood. The moment the proportion of carbonic acid in the blood circulating through the medulla is increased, the respiratory centre becomes more active and gives off more rapid messages to the muscles of respiration. Whenever we begin to move about quickly the muscles give off more carbonic acid, and it is because this stimulates the respiratory centre that we breathe more rapidly during exercise.

The Cerebellum.—To judge from its size the cerebellum must be a very important organ, but its functions are not yet thoroughly known. It will be sufficient here to say that it has a good deal to do with the balancing of the body. It is very large in birds, which are adepts at balancing. Occasionally a tumour grows in the cerebellum, and when this occurs one of the earliest symptoms is a reeling gait like that of a drunken man.

The Great Brain.—All the higher nervous functions—con-

sciousness, will, reason, speech, sight, hearing, taste, smell, touch—depend upon the integrity of the brain. The physical basis for these functions is furnished by the gray matter of the cortex. Certain parts of the cortex are known to be specially concerned with particular functions. The principal

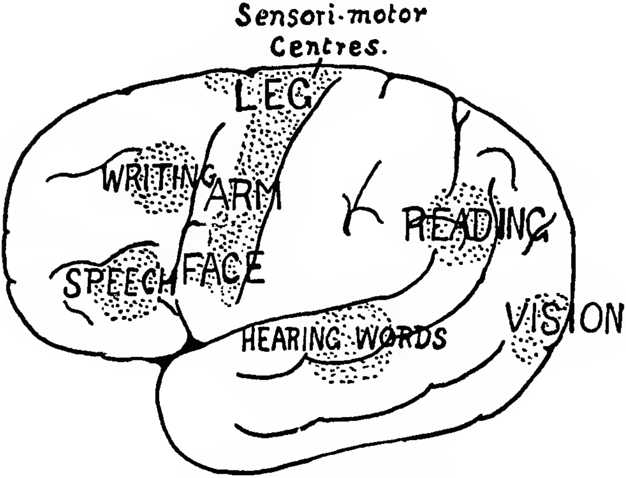

FIG. 78. Left cerebral hemisphere to show the chief "centres." The association areas are unshaded.

centres of this kind are shown in Fig. 78. Large areas of the cortex, however, amounting to about two-thirds of the whole, cannot be marked out in this way with any definiteness; and it is believed that these may be the seat of the intellectual faculties, or that they may be concerned in what psychologists call association.

The functions of the brain have been studied by experiments on animals, by observations made during surgical operations, and by carefully studying the symptoms in cases where the brain was affected by disease, such as tumour or apoplexy, and comparing these with the changes found in the brain after death.

Perhaps our most definite knowledge is of the **motor functions of the brain.** If an electric current is applied to any part of the motor area of the cortex the result is a movement of some part of the body on the opposite side. If the whole area were destroyed by the rupture of a blood-vessel (which is the common cause of apoplexy) the patient, if he did not die, would be paralysed in his face, arm, and leg on the opposite side to the damage.

Various parts of the motor area are concerned with definite parts of the body. If the part marked LEG, for example, in the diagram were alone destroyed, the paralysis would be confined to the leg on the opposite side.

In this motor area there are large nerve cells similar to those in the anterior horn of gray matter in the spinal cord. The axons from these cells pass out of the gray matter into the central mass of white matter. Through this they can be traced right down through the pons, and into the medulla. It is here that most of the fibres cross over to the opposite side, those from the right side of the brain crossing to the left, and those from the left to the right. A few fibres, however, pass down into the cord on the same side, but ultimately they cross over also.

If we continue to trace out these motor fibres we find that, unlike those coming from the motor cells of the cord, they do not pass out into nerves. On the contrary, they leave the white matter to turn into the central gray matter of the medulla or the cord. There they break up into fine branches which bring them into relationship, though probably not into contact, with the motor cells from which the nerves arise. Thus the fibres which come from the arm area pass down as far as the upper part of the cord from which come the nerves of the arm. The fibres from the leg area pass right down the cord and come into relationship with the cells concerned in leg movement.

The part played by these lower cells in reflex action has

been described. We can now understand that these cells may be caused to discharge, not only by sensory messages,

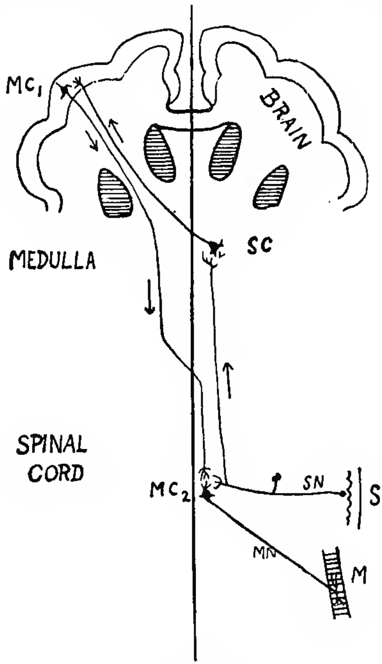

FIG. 79. Diagram to illustrate the course of the nerve fibres. MC_1. A motor cell in the gray matter at the surface of the brain. Its axon passes through the white matter of the brain, between two of the basal ganglia, to end in the gray matter of the cord on the opposite side, near MC_2, a motor cell in the spinal cord, whose axon passes into the motor nerve MN, to end in the muscle M. S. Skin. SN. Sensory nerve fibre, passing to the spinal cord, where it divides into branches near the motor cell, MC_2, and the sensory cell, SC, from which an axon passes to the gray matter of the cortex of the brain.

but by messages from the brain. This is what happens in voluntary movement. A nervous impulse from some part of the motor area of the brain passes down through the white matter of the brain and cord and causes the motor cells of the lower level to send a nerve current to the muscles.

The Sensory Nerve Fibres.—It will be remembered that we described the sensory nerve fibres which pass into the cord as ascending towards the brain and giving off branches which come into relationship with the motor cells of the anterior horn of gray matter. These sensory fibres pass right up through the cord and medulla into the brain and are ultimately brought into relationship indirectly (that is to say, by the intervention of other nerve cells and their axons) with the motor cells of the cortex. Hence what has been called the motor cortex would be more adequately designated sensori-motor.

The Speech Centres.—The first step in the localisation of the function of speech was made by a French physician, Broca, who discovered in 1861 that the destruction of a small area on the left side of the brain resulted in the loss of speech. Since then it has been discovered that speech depends upon several centres, all of which are situated in the left cerebral hemisphere in the case of right-handed persons, but in left-handed people the corresponding centres are in the right hemisphere.

The centres for speech are as follows (*see* Fig. 80):

1. The first motor speech centre concerned in talking (Broca's convolution).
2. The second motor speech centre concerned in writing.
3. The auditory speech centre concerned in hearing.
4. The visual speech centre concerned in reading.

The two latter constitute the sensory speech centres.

If any of these centres are destroyed by disease, the patient is unable to speak or to write, to understand or to read, according to the centre affected. If centre 3, for example, is damaged the patient can hear quite well, but he cannot understand; if the fourth centre is affected print can be seen, but it looks like a foreign language.

These centres are closely connected in their activities, the

most intimate relations being between 2 and 4, as in writing, and 1 and 3, as in conversation. Besides such direct relationships the various centres may be thought of as associated in

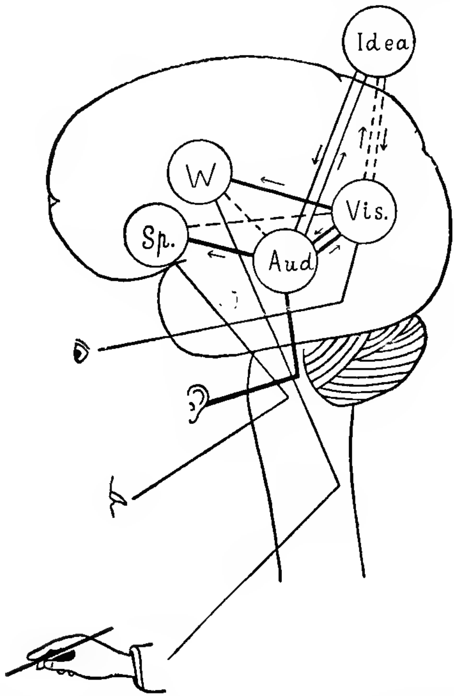

FIG. 80. Diagram showing speech centres. Sp. Centre for speaking. W For writing Aud. For hearing Vis. For reading. Idea. The hypothetical idea centre, drawn outside the brain

common with a still higher centre called the idea centre. Any word that we hear or read calls up old associations and memories and an idea is formed in our mind, and this idea may direct our speech or our pen. There is nowhere in the brain, however, a defined area in which ideas are formed. The conception of an idea centre is simply a hypothesis to enable us to picture to ourselves the working of the four speech

centres which have been pröved to exist. In the diagram the idea centre is drawn outside the brain to show that it is

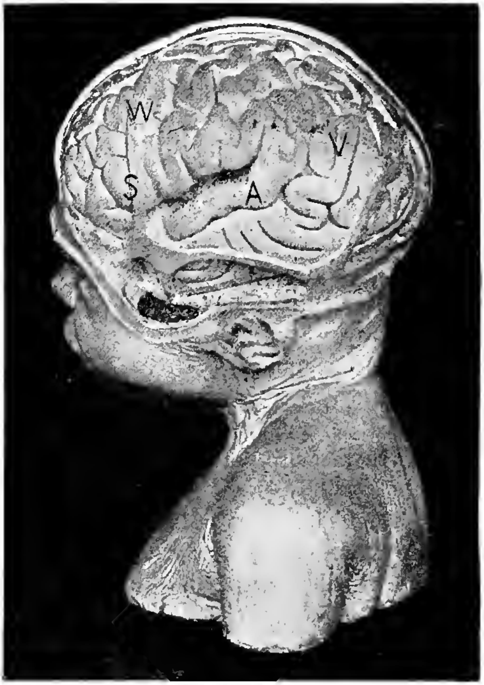

Fig. 81. Brain of a child showing language centres S. Speaking. W. Writing. A. Hearing. V. Reading.

different from the other centres referred to, whose situation we know.

The speech centres develop during infancy and childhood. During the first few months of life discharges from the chief motor centre cause the babbling of the infant, while a few frequently repeated sounds impress themselves upon the auditory word centre and come to be recognised by the child. At the end of the first year quite a number of words

awaken definite ideas—of going out, of being fed, of familiar objects.

At first the centres are not connected together, but this association begins during the first year and proceeds rapidly during the second, so that the child learns to repeat words he hears or to use words appropriate to the ideas in his mind.

When the child learns to read the visual word centre is formed. It is somewhat apart from the ordinary visual centre by which objects seen are recognised, and it is closely related with the auditory word centre. During learning, the words seen on the page are associated with words spoken by the teacher. That is to say, an association is formed between the visual speech centre and the auditory speech centre of the child. Subsequently, when the words are seen they awaken sound memories in the auditory centre. Thus the ideas connected with the words are called up, and the child understands what he reads. Later the writing centre is developed, and in it are stored the memories of how words are produced in writing.

Inhibition.—The higher parts of the nervous system assert a controlling influence over the lower. For example, if an injury crushes a small part of the spinal cord, the reflex movements below the seat of the injury become more active because the restraining influence of the brain is shut off. This restraining power is termed inhibition. A higher form of inhibition is seen when a young child learns to control his naturally impulsive movements. The power of controlling our actions in accordance with the teaching of experience is one of the main results of education. It is by the development and exercise of this power that a child is gradually converted from a creature of impulse into a rational being who can act from deliberation and choice.

The "Level" Theory of Nervous Action.—The nervous system is sometimes represented as a kind of hierarchy in which certain groups of cells exercise direction or control over

others. The best known theory of this kind recognises *three levels* of nervous activity. The *lowest* is that which is concerned with reflex movement, including the movements of the heart and of respiration. The nerve cells of this group are those of the medulla and spinal cord. The *second* level is concerned with the more complex *automatic* movements—movements which had to be learned, but which have been so perfected by practice as to require a minimum of conscious attention. The nerve cells of the sensori-motor cortex, and probably of the basal ganglia, belong to this level. At the *third* level we place the highest functions of the brain—amongst them Will. In a voluntary movement an impulse passes from the cells of the motor cortex. What makes it pass? Theoretically there must evidently be a third level of function, but the physiologist can only locate its seat vaguely as being in some part of the cortex not occupied by the motor or special sense centres which he has marked out.

The cells belonging to the third level are very sensitive and their functions are very easily interfered with. This occurs, for example, in sleep. In very deep slumber the cells of the second level are affected also, but in lighter sleep they are sufficiently active to enable the sleeper to turn in bed, and perhaps even to respond to a question without awaking. In somnambulism the second level cells are so active that the sleeper may get up, dress, and walk about without being aware of what he is doing.

The sensitiveness of the highest level cells is also shown by the effects of a blow on the head, which abolishes consciousness; or of drugs such as alcohol, morphia, or chloroform.

This theory, which is associated with the name of the late Dr. Hughlings Jackson, is based upon the study of disease, but it is supported by recent observations upon the development of the brain after birth. In the infant at the time of birth there are many tracts in which the white sheaths of the nerve fibres are wanting. The fibres, as it is expressed, are

not *medullated.* In some places the fibres become medullated earlier, and in some later. Now it is believed that these fibres cannot properly carry nervous currents, that is to say, that they do not become functional, until they acquire their white sheaths.

At birth medullation is complete in the fibres which convey impulses to and from the cells of the spinal cord. This agrees with the observation that the new-born child is a "spinal animal"—that its movements are of the reflex kind.

After birth the medullation of the great tracts which connect the sensori-motor area of the brain with the cord proceeds rapidly. Medullation also occurs between the sense organs and their centres in the cortex. This corresponds with the development of motor power and of the senses in infancy and early childhood.

At a later period fibres develop which extend from a large part of the surface of the brain, especially from the front and from the back of the cerebrum, not to lower parts of the nervous system, but to other parts of the cortex—namely, to the sensori-motor area and to the various sense centres. The parts of the brain from which these fibres come are of large size, involving about two thirds of the cortex, and Flechsig has put forward the very interesting theory that these areas are specially concerned with association and with the higher mental functions.

GENERAL SUMMARY OF THE FUNCTIONS OF THE NERVOUS SYSTEM

The *nerves* convey messages from the body to the spinal cord and brain, or from the brain and spinal cord to the different parts of the body.

The *spinal cord* is the chief centre for reflex action.

The *medulla* is also a centre for reflex action, and contains

the nerve cells concerned in the movements of the heart, and of respiration.

The *cerebellum* is concerned in balancing the body.

The *cerebrum* is the seat of consciousness, intelligence, memory, will. It receives the messages which are interpreted as touch, pain, taste, smell, hearing, sight. It originates impulses which lead to action. These functions reside in the grey matter of the cortex, and are dependent on the activity of nerve cells which are grouped together in numerous "centres." The highest functions require the associated activity of a number of these centres.

APPENDIX

I.—THE EXAMINATION OF THE URINE

1. Measure the total *quantity* passed in twenty-four hours, and set up a specimen in a urine glass. (Average quantity 50 ounces.)

2. Observe the *colour*.

3. Test the *reaction*. Acid urine turns blue litmus paper red; alkaline urine turns red litmus blue.

4. Test the *specific gravity* by floating a urinometer in the urine. To read the scale place the eye level with the surface of the urine. Normal specific gravity, 1015 to 1025.

5. Note the amount and character of the *deposit* after the urine has stood for some time. The chief deposits are:

Mucus. A transparent or semi-transparent cloud.

Urates. A "brick-dust" deposit (occasionally yellowish, or even colourless). Occurs in acid urine. Disappears if the urine is heated.

Phosphates. A whitish flocculent deposit in neutral or alkaline urine. Soluble in acetic acid.

Pus. A compact whitish deposit resembling phosphates, but not soluble in acetic acid. Becomes ropy on the addition of caustic potash.

Uric Acid. A scanty deposit of reddish-brown grains like cayenne-pepper.

Oxalates. Colourless crystals usually entangled in a cloud of mucus.

6. *Albumin*. Occurs in Bright's disease. Before testing, the urine must be filtered if it is cloudy, and if it is alkaline just sufficient acetic acid must be added to make it *faintly* acid.

(*a*) Fill a test-tube half full of urine. Holding the tube by the bottom heat the central portion to boiling. If it remains clear no albumin is present. Turbidity may be due to albumin or earthy phosphates. Add one drop of nitric acid and shake gently. Phosphates dissolve at once. Any remaining turbidity is due to albumin. A very slight cloud can be seen by comparing the heated portion with the cool portion against a dark background.

(*b*) Place 1 inch of urine in a test-tube, slope the tube, and allow nitric acid to flow down the side of the tube *very gently*, so as to form a layer under the urine. If albumin is present a whitish ring appears at the junction of the two fluids.

7. *Blood.* A small amount of blood produces a "smoky" appearance in the urine. Place 1 inch of urine in a test-tube and add a drop or two of tincture of guaiac. A cloudy precipitate forms. Now add 1 inch of ozonic ether, without shaking. If blood is present a blue colour appears at the junction of the fluids. (Iodides in the urine, derived from medicine, also produce a blue colour.)

8. *Sugar.* If no diabetic urine is available for practising the tests, a little glucose may be dissolved in the urine. Cane-sugar will not do.

(*a*) *Trommer's Test.* Place 2 inches of urine in a test-tube, add $\frac{1}{8}$ inch of caustic potash solution. Drop in some 1 per cent. solution of copper sulphate and shake. A precipitate of cupric hydrate forms, which dissolves, producing a blue solution. Continue to add the sulphate of copper till some precipitate remains undissolved. Now boil the upper part of the mixture. It will become yellow and then red owing to the glucose reducing the precipitate first to cuprous hydrate and then to cuprous oxide. The yellow or red colour may be obscured by the formation of black cupric oxide if very little sugar is present.

(*b*) *Fehling's Test.* This is the usual test for sugar. Fehling's solution is a solution of copper sulphate, Rochelle salt, and caustic soda in definite proportions. Place 1 inch of fresh Fehling's solution in a test-tube and boil. It ought to remain clear. Add a few drops of urine and boil again. If much sugar is present a yellow or red precipitate will appear. If no precipitate forms add as much urine as there is Fehling and boil again. If the mixture remains clear after standing for a few minutes no sugar is present.

(*c*) *Fermentation Test.* This is the most certain test for sugar. The urine is boiled thoroughly, cooled, mixed with a little fresh yeast, and set aside in a warm place in a fermentation tube. If sugar is present fermentation will take place, and carbonic acid gas will collect in the tube.

9. *Bile.* The urine is greenish or brownish-yellow, and if shaken up a persistent froth forms on the top. Place a large drop of the urine and a drop of strong (fuming) nitric acid on a white tile. Allow the drops to run together, and a play of colours—red, violet, green—will be seen, owing to oxidation of the bile pigment.

II.—SOME WEIGHTS AND MEASURES

1 ounce	= 437.5 grains.
1 pound	= 16 ounces, or 7000 grains.
1 minim	= 0.91146 grain.
1 gram	= 15.432 grains.
1 kilogram	= 2 lb. 3 ounces.
1 c.c., *i.e.* cubic centimetre	= 16.9 minims.
1 litre	= 1000 c.c., or 35.2 fluid ounces.
1 pint	= 20 fluid ounces.
1 fluid ounce	= 8 fluid drachms.
1 fluid drachm	= 60 minims.

An ordinary teaspoon holds about 1½ to 2 fluid drams; a tablespoon holds about 1 fluid ounce.

A halfpenny measures 1 inch in diameter and weighs $\frac{1}{5}$ ounce.

III.—CENTIGRADE AND FAHRENHEIT SCALES

To convert Fahrenheit into Centigrade, subtract 32, multiply the remainder by 5, and divide the result by 9.

To convert Centigrade into Fahrenheit, multiply by 9, divide by 5, and add 32.

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